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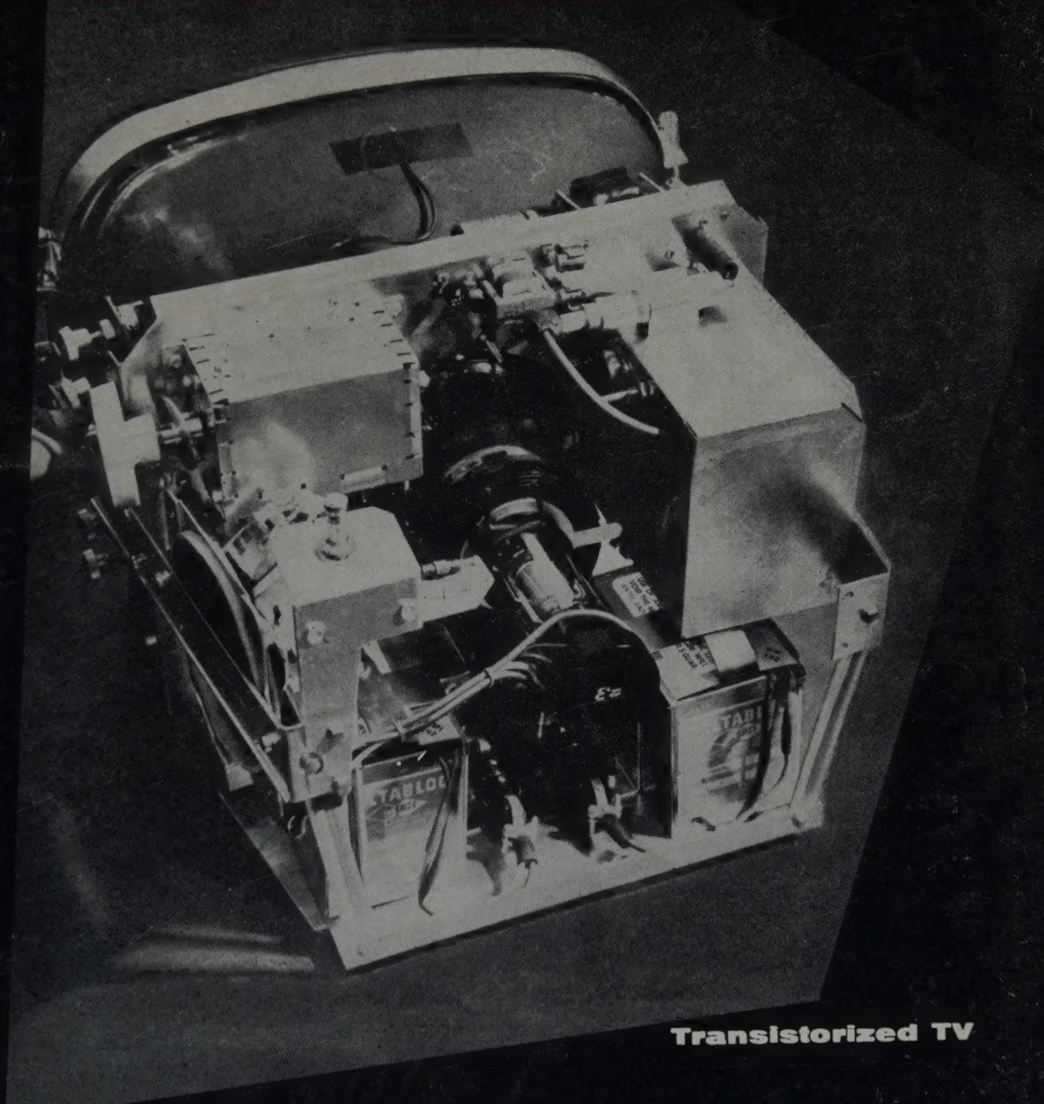

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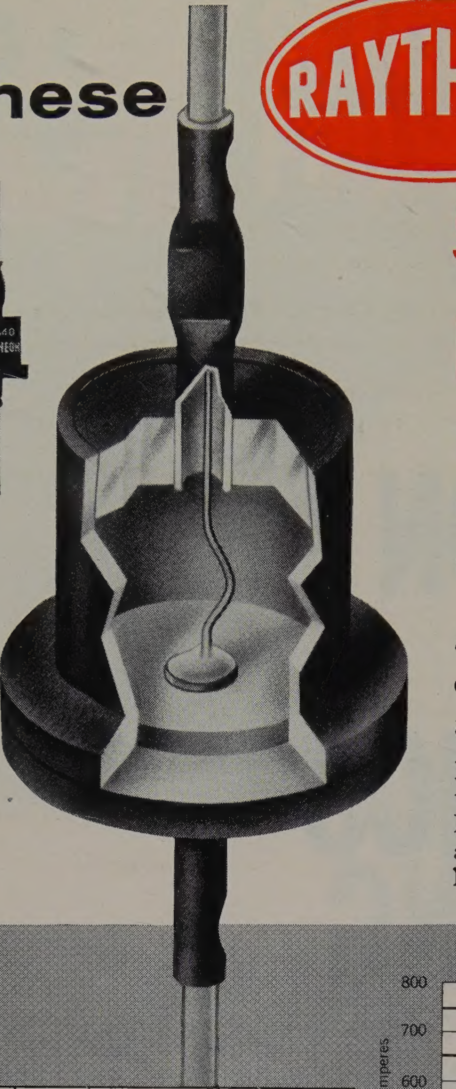

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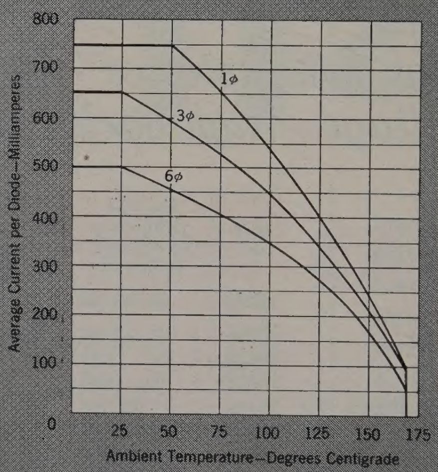

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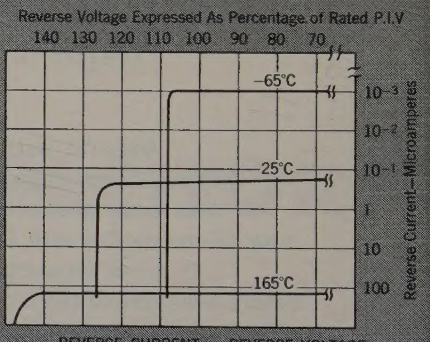

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SEMICONDUCTOR PRODUCTS

SANFORD R. COWAN, Publisher

Mar./Apr. 1958 Vol 1, No. 2

Front Cover

Chassis of Motorola's transistorized battery-operated portable TV receiver shows that the only tube employed is the picture tube. Further information on this receiver is described in an article beginning on page 21 of this issue.

ARTICLES APPEARING IN THE NEXT ISSUE

High-Current Switching Applications of Low-Power Transistors
Transistor Servo Amplifier Output Stages
A Germanium Alloy Transistor for High Temperature Operation
Hole Storage Delay Time and its Prediction
Design Criteria for Transistor Prosthetic Devices
Tantalum Capacitors

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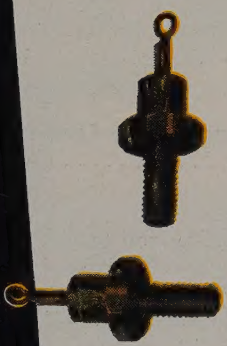

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Guest Editorial . . .

EDITOR'S NOTE

From time to time we will provide our readers with a Guest Editorial on a subject of immediate interest. In this issue it is with great pride that we turn over our editorial page to Dr. William Shockley who discusses Zener and avalanche effects. It might be significant in this regard that one of the charts published in this issue has a heading entitled "Characteristics Chart of Silicon Zener or Avalanche Diodes." In keeping with this designation, one of the subheadings is listed as "Zener or Avalanche Voltage Range." Following Dr. Shockley's contribution, we include a letter from Dr. Clarence Zener commenting on the sum and substance of the editorial.

S.L.M.

One of the new and useful semiconductor devices developed as a result of the growth of transistor electronics is the so-called Zener diode. The Zener effect is now known to play no important role in diodes of this type, except possibly for some which have especially low breakdown voltages. The effect which gives them their voltage-limiting character is the avalanche effect. The relationship between the two effects is discussed in an article by Dr. A. G. Chynoweth in this issue of SEMICONDUCTOR PRODUCTS.

As the person most responsible for this misnomer, I should like to contribute to setting the terminology straight. There are two particularly compelling reasons: First, a misnomer is a bad thing in itself, and second, the true Zener effect does occur, and the name should be reserved for the important process proposed by Zener in 1934.

The Zener effect was originally proposed by Clarence Zener while he was a fellow at the University of Bristol in England. A few items of Zener's career history may be appropriate here. He is a domestic product, having been born in Indianapolis, Indiana. He was educated at Stanford and Harvard and has held academic posts and fellowships in the United States and abroad. He was at Watertown Arsenal from 1942 to 1945, and principal physicist there in 1944-1945. He was professor of physics at the University of Chicago from 1945 to 1951, when he left to become associated with the Westinghouse Research Laboratories in Pittsburgh, where in 1956 he was made Director.

My own interest in the critical-voltage diode was stimulated by some observations made by colleagues at Bell Telephone Laboratories in about 1951. These observations showed that the reverse voltage characteristics had rapidly increasing currents. It appeared that a useful voltage-limiting device might be produced. I was alert to this possibility as a result of a discussion I had heard several years before from Dr. O. E. Buckley, then president of Bell Telephone Laboratories. Buckley pointed out the need for a better lightning-protection device for rural telephones. It seemed to me that a silicon *p-n* junction might be an excellent answer.

Some diodes with sharp breakdown characteristics were successfully produced and appeared to fit with the Zener theory. Professor Frederick Seitz suggested that the effect might actually be due to avalanche. This possibility was tested by finding out if a photocurrent was amplified when the voltage was raised into the breakdown range. No amplification effect was observed and, accordingly, my colleagues and I concluded that the high reverse currents were not produced by secondary multiplication but, instead, by the Zener effect. We published this conclusion in a letter to the PHYSICAL REVIEW (Phys. Rev. 83, 650, 1951), and a patent application was filed, proposing the Zener effect as the probable mechanism giving the voltage-limiting action (W. Shockley 2,714,702). We also promulgated the name "Zener diode" for the device.

What apparently had occurred in our *p-n* junction was avalanche multiplication at points so far from the surface that no current produced by the light reached these points.

The situation has since been clarified, chiefly by K. G. McKay of Bell Telephone Laboratories and his co-workers.

From a personal point of view, I regret having contributed to flubbing a scientific conclusion. However, I do not regret having published when we did. I prefer to bring out a useful and provocative observation early, that may be used as a stepping stone by others who will advance by correcting possible errors, than to hold back a result until absolute assurance can be achieved.

In this instance, however, I do hope that in justice to both the Zener effect and the avalanche effect, the confusion in names can be corrected.

Wm. Shockley

Dear Mr Marshall:

Dr. Shockley has sent me his correspondence with you in regard to the nomenclature of semiconductor diodes. I heartily agree wtih Dr. Shockley that misnomers should be corrected and hope that you will take a lead in this direction.

Sincerely,
Clarence Zener

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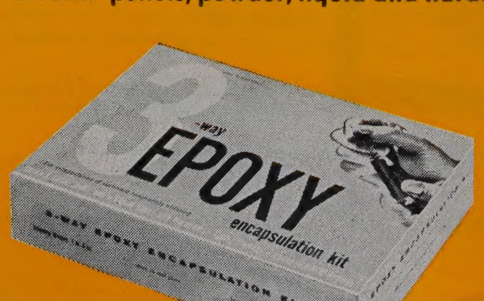

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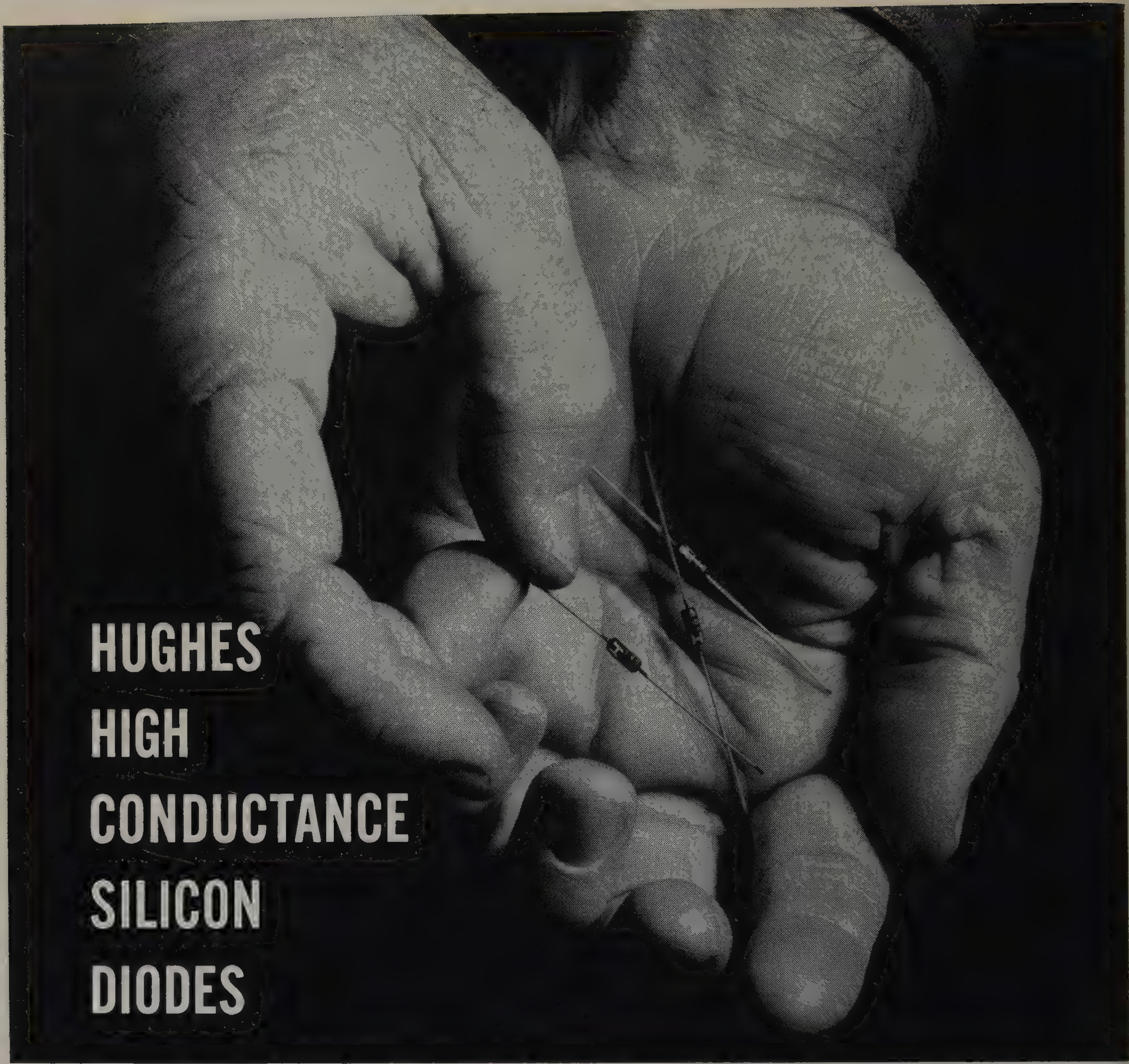

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Type Number*	Max. Forward Current @ +1 Volt	Max. Rated Average Forward Current @ 25°C	Max. Rated Average Forward Current @ 150°C	Max. Inverse Current @ 25°C	Max. Inverse Current @ 150°C	Max. Inverse Current Test Voltage	Max. Rated Inverse Operating Voltage
1N482B	100mA	200mA	50mA	.025μA	5μA	30V	36V
1N483B	100mA	200mA	50mA	.025μA	5μA	60V	70V
1N484B	100mA	200mA	50mA	.025μA	5μA	125V	130V
1N485B	100mA	200mA	50mA	.025μA	5μA	175V	180V
1N486A	100mA	200mA	50mA	.050μA	25μA	225V	225V
1N487A	100mA	200mA	50mA	.100μA	25μA	300V	300V

(*Lettered and unlettered versions not listed are available.)

Hughes has related types with higher forward currents. Here are three of the many which could be listed:

HD6764	200mA	200mA	50mA	.025μA	5μA	60V	70V
HD6768	200mA	200mA	50mA	.025μA	5μA	175V	180V
HD6773	200mA	200mA	50mA	.025μA	5μA	300V	300V

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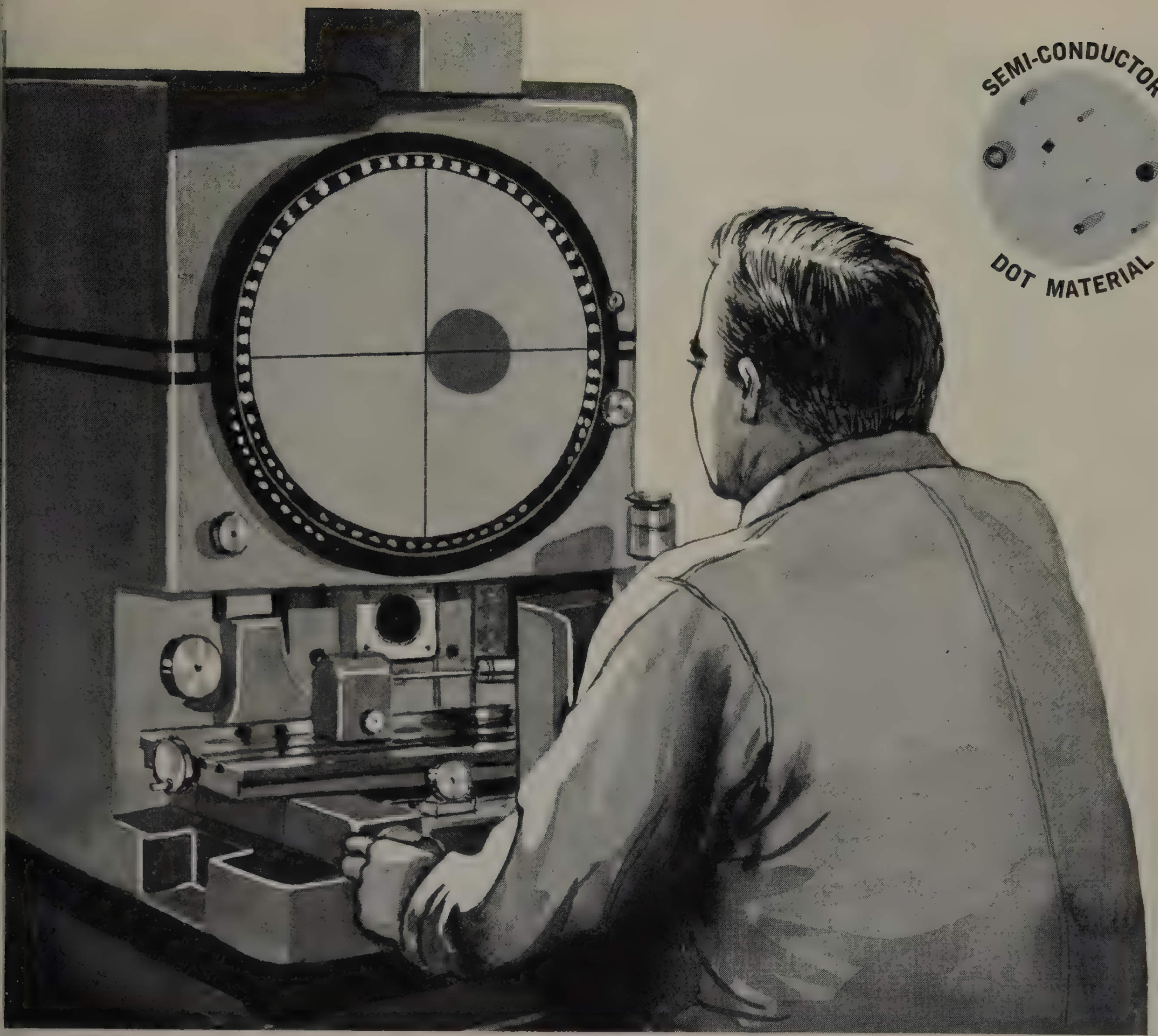

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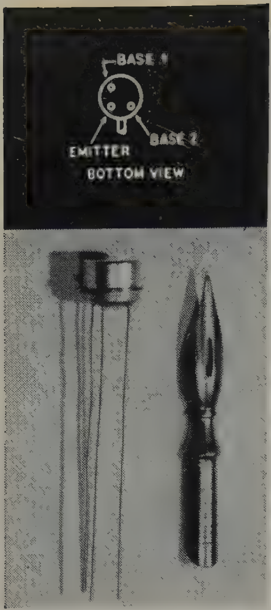

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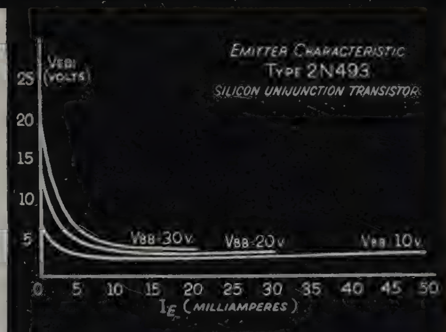
SPECIFICATIONS OF THE SIX SILICON UNIJUNCTION TYPES

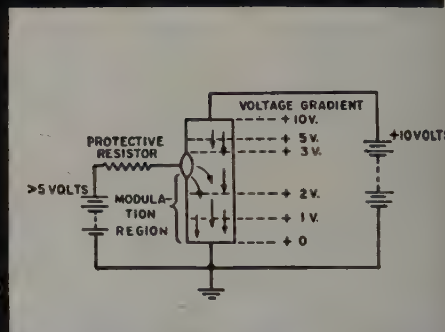
Absolute maximum ratings (25°C)

RMS power dissipation	**250 mw**
RMS Emitter current	**50 ma**
Peak emitter current	**2 amps**
Emitter reverse voltage	**60 volts**
Operating temperature range	**—65°C to 150°C.**
Storage temperature range	**—65°C to 200°C.**

Major electrical characteristics (nominal)

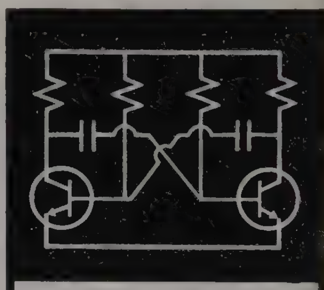
	2N489	490	491	492	493	494	
Interbase resistance at 25°C junction temp.	**5.6**	**7.5**	**5.6**	**7.5**	**5.6**	**7.5**	**kΩ**
Intrinsic standoff ratio	**.56**	**.56**	**.62**	**.62**	**.68**	**.68**	
Modulated interbase current	**12**	**12**	**12**	**12**	**12**	**12**	**ma**
Emitter reverse current (T_J=25°C)	**.07**	**.07**	**.07**	**.07**	**.07**	**.07**	**μa**
(T_J=150°C)	**28**	**28**	**28**	**28**	**28**	**28**	**μa**

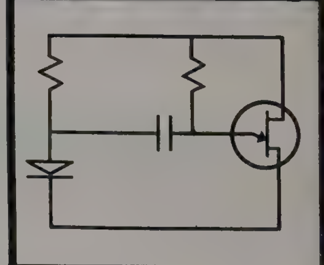




The unijunction consists of an "N" type silicon bar mounted between two ohmic base contacts, with a "P" type emitter near base 2. When the emitter is forward biased, emitter current flows, lowering the resistivity of the bar between emitter and base. Inherent regeneration results in a negative emitter to base 1 impedance. As the emitter current increases past the valley of the curve, the conditions for inherent regeneration cease to exist. The curves show emitter characteristics in the negative resistance region for different base to base voltages.

Among the many simplified circuits possible with the unijunction (cutting transistor requirements in half) are a frequency divider, matrix switching circuit, low level d-c current-sensing circuit, temperature control element, phase and/or amplitude sensitive switch. The conventional multivibrator circuit (above right) requires even more circuitry than is shown if it is to be as stable as the comparable unijunction circuit shown below. A relaxation oscillator usually takes 4 resistors, 2 transistors and a capacitor. A single unijunction, a resistor and capacitor will do the equivalent job.





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70 MC SILICON TRANSISTOR

CHARLES EARHART* and WILLIAM BROWER†

Design considerations, device fabrication, electrical test methods, and typical electrical characteristics of a newly developed n-p-n silicon tetrode transistor made by the grown-diffused technique.

INTRODUCTION

IN AUGUST, 1957, the commercial availability of a 70 megacycle silicon *i-f* transistor, type 3N35 was announced.[1] This newly-developed device is an *n-p-n* silicon tetrode transistor made by the grown-diffused technique. Typical device power gains of 18-20 *db* may be obtained as double-tuned neutralized amplifiers, and alpha-cutoff frequencies up to 400 megacycles have been noted. This high frequency performance approaches that obtainable from the best germanium transistors currently available while offering the important high temperature advantages of silicon to the user.

In the following discussion a general description of the transistor design and fabrication is given with particular emphasis on those factors which are important at high frequencies. Electrical testing methods and results are explained, following which typical high frequency characteristics of the new transistor are presented.

Design Considerations

Considerable past experience with grown-junction silicon tetrode transistors indicated that this well-known device was extremely satisfactory as a small-signal amplifier at frequencies up to 30 megacycles. Investigation of its performance at higher frequencies showed, however, that considerable improvement in the transistor design would be necessary in order to achieve dependable operation at 70 megacycles.

It was realized that the first design goal was to increase alpha-cutoff, or $f_{\alpha b}$, to 150 megacycles or higher. The development of the grown-diffused technique of crystal growing by Dr. Willis Adcock and Mr. Boyd Cornelison of Texas Instruments[2] made it possible to utilize the principles of solid state diffusion to produce *n-p-n* silicon crystals with the required thin base layers.

A second objective was the lowering of collector capacity, C_c, to approximately 2 $\mu\mu f$. This was accomplished by a reduction of the transistor bar size to approximately 7 x 7 mils square. The resulting slender transistor element caused an increase in R_{cs}, the collector series resistance, and gave rise to a correspondingly large time constant in the collector output circuit which seriously limited high frequency performance. The problem was solved by alloying ohmic contacts to the collector and emitter regions within a distance of 1 or 2 bar diameters from the base layer.

Finally, the tetrode principle[3] was utilized by applying a potential across the base region, using the added base connection, to improve the high frequency performance of the transistor.

Device Fabrication

Fabrication of the 3N35 transistor originates with the growing of an *n-p-n* silicon crystal containing the collector, base, and emitter regions. The junctions are produced by the grown-diffused technique, which operates in three steps as shown in *Fig. 1*. First, the collector region is grown in a conventional manner. Next, growth is stopped while emitter and base producing impurities are added, after which growth is resumed. Finally, a suitable length of emitter region is grown, during which time both the emitter and base producing impurities diffuse upward into the collector region. Because acceptor impurities diffuse more rapidly than donors in silicon, a narrow *p*-type base layer is formed between the emitter and collector regions. The thickness and conductivity of this base layer depend upon the relative doping levels, upon the impurities used, and upon the growth rate and time taken to grow the emitter region. Since diffusion

---

* *Assistant Chief Engineer, Contract Projects, Texas Instruments Incorporated*

† *Project Engineer*

[1] *Texas Instruments Incorporated announcement*

[2] *Boyd Cornelison and Willis A. Adcock: "Transistors by Grown-Diffused Technique", Wescon Meeting, 21 August 1957.*

[3] *R. L. Wallace, L. G. Schimpf, and E. Dicten: "A Junction Transistor Tetrode for High Frequency Use", Proc. IRE, Vol. 40, pp. 1395-1400, 1952.*

akes place from impurities which are already inside he solid crystal, the process is not affected by variaions in surface properties or concentrations, and xtremely close control of crystal characteristics is eadily maintained.

Each crystal is cut to yield a large number of n-p-n ars which are fabricated into transistors as shown in *ig. 2*. Ohmic supporting contacts consist of platinum abs, overlaid with antimony-doped gold, which are lloyed to the 7 x 7 mil silicon bar. Base contacts are nade by alloying 2½ mil diameter aluminum wires o opposite sides of the p-layer. The platinum tabs re spot welded to the header, and the base wires are oldered in place. After final surface treatment, the ompleted assembly is encapsulated by welding a can ver the header to obtain a hermetic seal. The finished ransistor as shown in *Fig. 3* corresponds to the proosed JETEC Group 30 outline specifications.

lectrical Test Methods

The methods used for characterizing 70 megacycle etrode transistors at high frequencies have been hosen to yield the parameters of greatest usefulness o the circuit designer, and at the same time to provide parameters that are adaptable to rapid and preise measurement by the manufacturer.

In most high frequency applications power gain is he factor of primary interest, with band width and transistor parameter variations being other important considerations. As transistors become available having average gains somewhat above the desired minimum values, the circuit parameters become more important than gain to the user, since interchangeability is affected more by parameter variation than by gain. Also, variations in characteristics are more difficult for the user to evaluate.

Power gain may be calculated from basic measured parameters in a variety of ways[4, 5] but the one found most convenient at 70 megacycles is by use of the following equation, which assumes conjugate matching of the input and output with lossless neutralization. The derivation of this equation is given in Appendix A.

$$P.\,G. = \frac{|h_f|^2}{4h_i^R \quad y_o^R} \qquad (1)$$

where:

h_f = short-circuit forward current gain
h_i^R = Real part of the short-circuit input impedance
y_o^R = Real part of the short-circuit output admittance

[4] *William D. Penn: "High Frequency Silicon Transistor Amplifiers", Great Lakes District Meeting of AIEE, 17 April 1956.*

[5] *R. R. Webster and R. F. Stewart: "Some Circuit Applications of Silicon Tetrodes", Wescon Meeting, 24 August, 1956.*

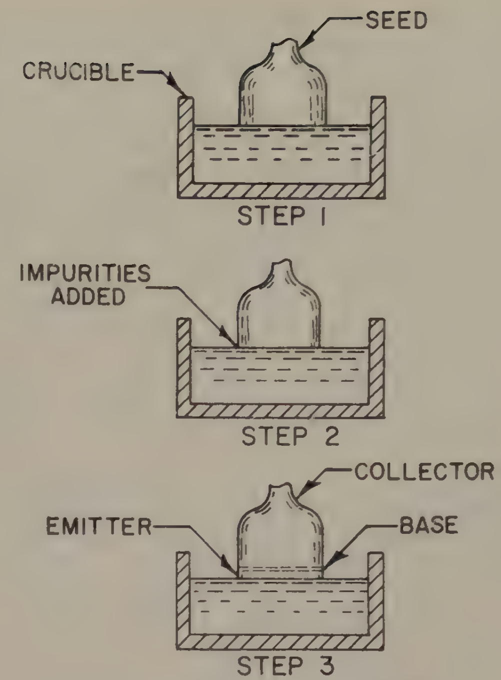


Fig. 1—Grown-diffused process.

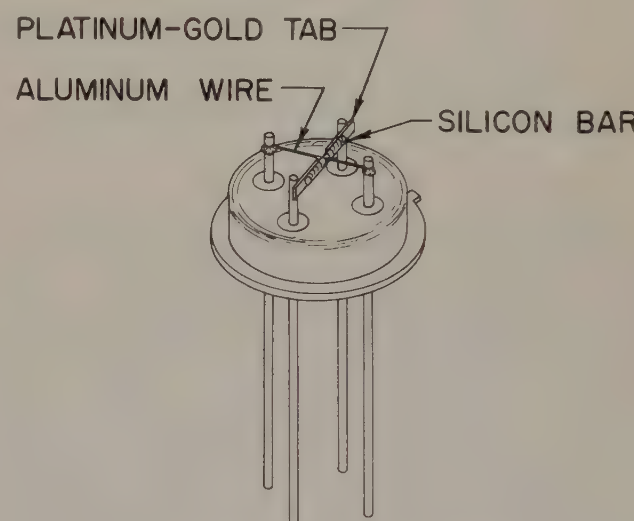


Fig. 2—70 mc transistor assembly.

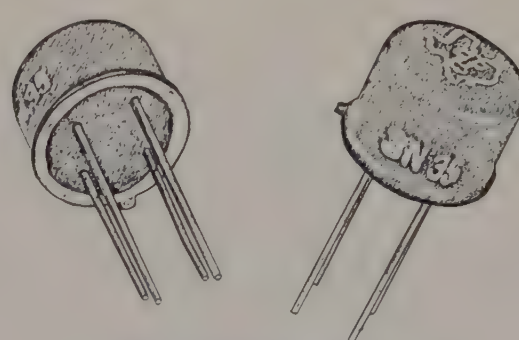


Fig. 3—Finished transistor.

At frequencies of 70 megacycles and higher, it is easier to make short-circuit than open-circuit measurements, and commonly available bridges in this range usually measure admittance parameters. The Boonton RX meter, which measures admittance in terms of parallel resistance and capacitance values, is a very convenient instrument for measurement of transistor input and output parameters. With this in mind, it is possible to re-arrange the power gain equation as follows:

$$P.G. = h_{fe} + 10 \log \frac{r_{oep}}{4 r_{ies}} \qquad (2)$$

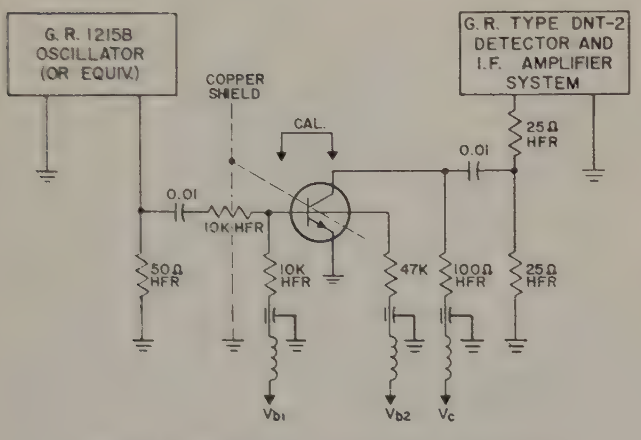


Fig. 4—High frequency h_{fe} test circuit.

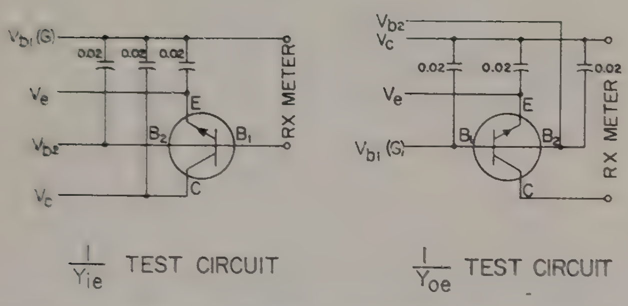


Fig. 5—Input and output parameter test circuits.

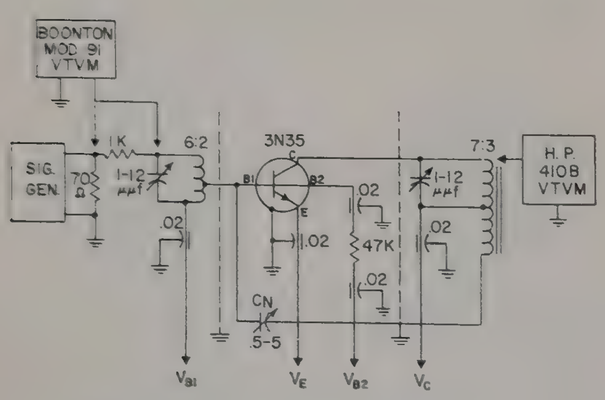


Fig. 6—70 mc power gain test set.

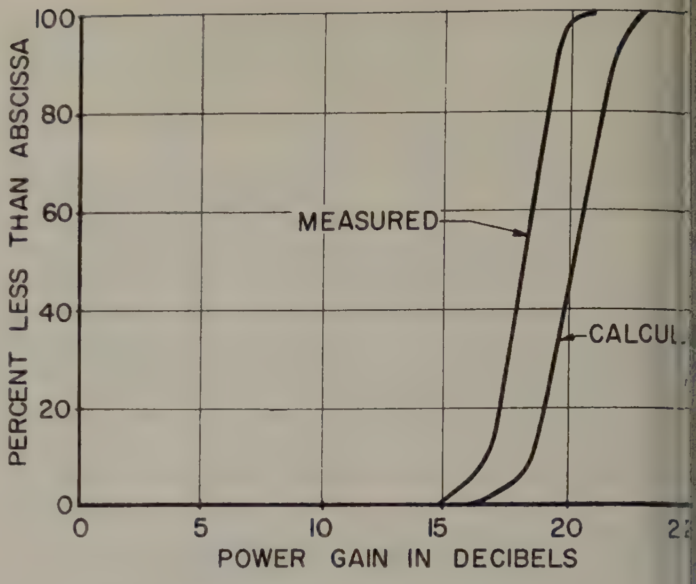


Fig. 7—Distribution of 70 mc power gain.

where:

h_{fe} = Common emitter short-circuit forward current gain in decibels.
r_{oep} = Common emitter parallel output resistance.
r_{ies} = Common emitter series input resistance.

The value of r_{ies} may be found from the equation:

$$r_{ies} = \frac{1}{g_{ie}\left[1 + \left(\frac{\omega C_{iep}}{g_{ie}}\right)^2\right]} \qquad (3)$$

where:

g_{ie} = Common emitter input conductance.
C_{iep} = Common emitter parallel input capacitance.

The common emitter series input resistance, r_{ies}, may also be obtained from the parallel input RX meter measurements directly by use of a simple series-parallel conversion chart.

It is thus seen that power gain at high frequencies may easily be calculated from measured input, output, and forward transfer parameters; parameters which are in themselves of great interest to the transistor user.

The forward transfer term, h_{fe}, is probably the most important single high frequency parameter. In the common emitter configuration, a useful approximation for alpha cutoff, $f_{\alpha b}$, may be obtained from the 6 *db*/octave frequency dependence of h_{fe} without adding another measurement and without the difficulty of direct alpha-cutoff determination at these frequencies. The circuit used in measuring h_{fe} is shown in *Fig.* 4. A General Radio 1215 B oscillator supplies a signal of the desired frequency, which is detected, amplified, and metered by the G.R. type DNT-2 De-

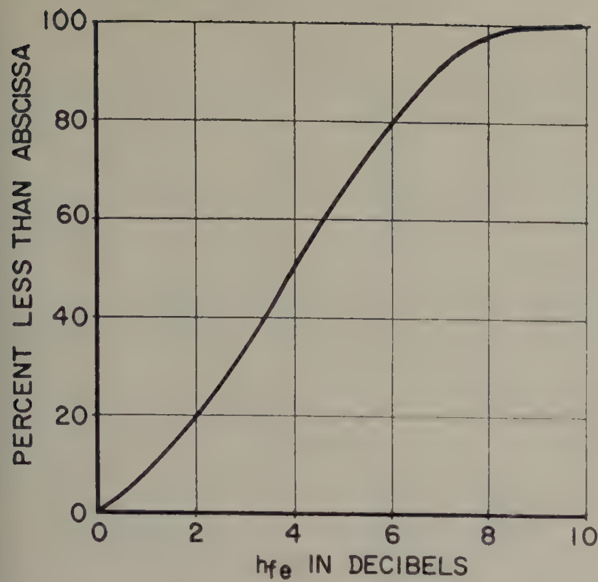


Fig. 8—Distribution of 70 mc h_{fe}.

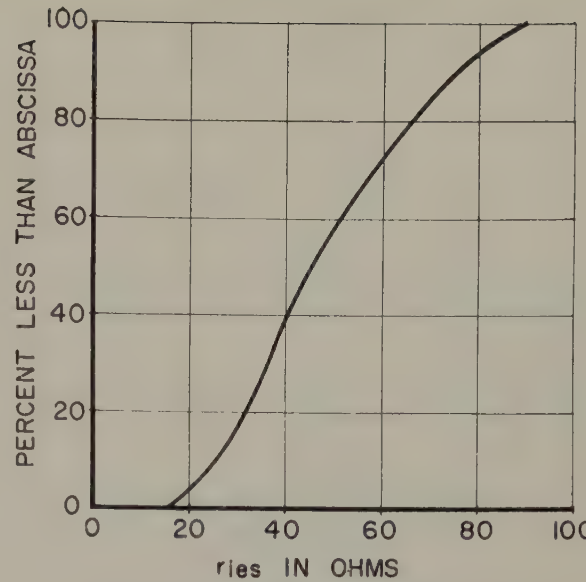


Fig. 9—Distribution of 70 mc r_{ies}.

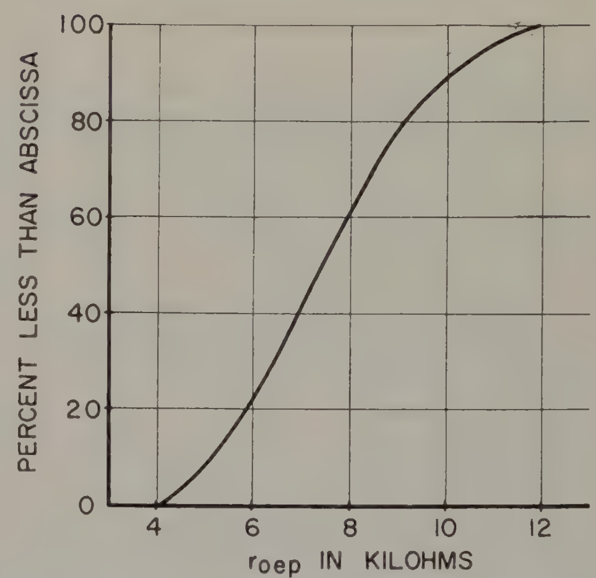


Fig. 10—Distribution of 70 mc r_{oep}.

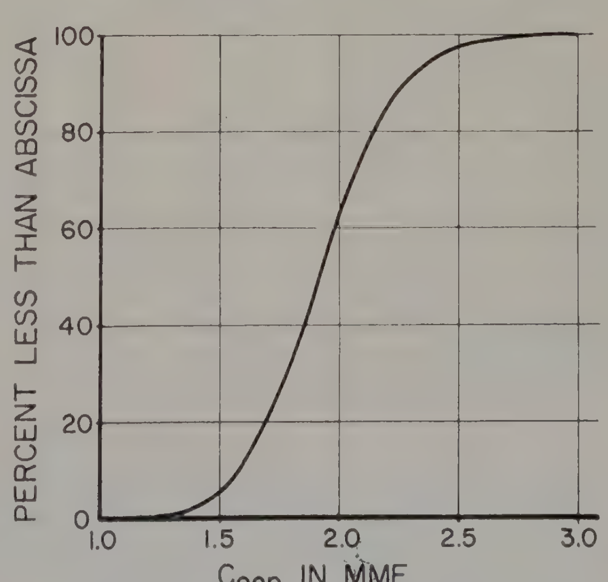


Fig. 11—Distribution of 70 mc C_{oep}.

tector System. The test jig is specially designed for good shielding and isolation between the input and the output circuits. A dummy shorted header is inserted in the socket to obtain a zero *db* reference level, after which, h_{fe} values may be read directly in decibels.

Parallel resistance and capacitance is measured on a Boonton RX Meter using test jigs designed for minimum lead or terminal inductances. *Fig. 5* shows the connection diagrams for the measurement of $1/Y_{ie}$ and $1/Y_{oe}$.

The direct measurement of power gain at 70 megacycles presents some difficulties, especially with regard to accurate determination of degree of neutralization, stray wiring inductances and capacitances, and tuning core losses. Careful measurements have been made on circuits such as that shown in *Fig. 6*. This test set is a common emitter feedback neutralized amplifier with tuned input and output. The degree of neutralization is indicated by the variation of input voltage as the output is detuned or short circuited. If the input and output impedances are known, the ratio of output voltage to input voltage can be used to determine the power gain.

Comparisons have been made between measured and calculated power gains at various high frequencies to determine the validity of the implicit assumptions made in the equation for power gain calculation. *Fig. 7* shows the distributions for both measured and calculated power gains at 70 megacycles for typical pilot production transistors. Looking at the figures for individual transistors, it is found that measured power gains are, on the average, approximately 2 *db* lower than calculated gains. The difference is attributed to mismatch and neutralization losses, which could easily be 1 to 2 *db*. It is felt that this correlation clearly establishes the usefulness of the power gain equation.

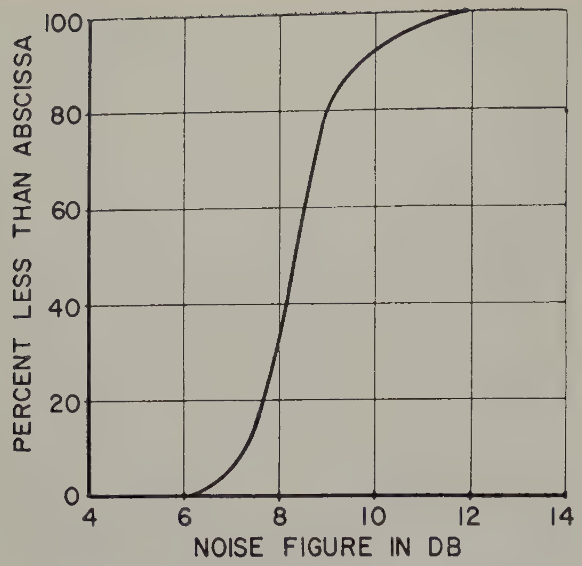


Fig. 12—Distribution of 70 mc noise figure.

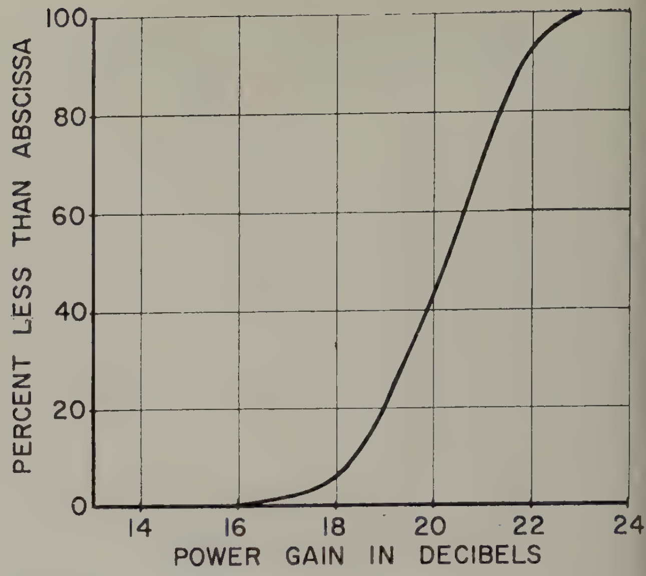


Fig. 13—Distribution of calculated 70 mc power gain.

Typical Electrical Characteristics

The electrical characteristics of the 3N35 70 megacycle transistor are presented in *Table I*.

Table I

3N35 ELECTRICAL CHARACTERISTICS

MAXIMUM RATINGS:

P_c (25° C) $= 125\ mw$
$BV_{ceo} = 30V$
$T_j = -65°$ to 150° C

PARAMETER	MIN.	DESIGN CENTER	MAX.	UNIT
I_{co} at $V_c = 20V$	—	—	0.2	μa
h_{fb} at Low Freq.	0.90	—	—	—
70 MC PARAMETERS:				
h_{fe}	1 (0 *db*)	1.6 (4 *db*)	—	—
r_{ies}	15	—	90	Ohms
r_{oep}	4K	—	15K	Ohms
c_{oep}	—	—	3.0	μμf
N. F.	—	—	14	*db*
P. G.	15	—	—	*db*

CONDITIONS:

$V_c = 20V, I_e = -1.3\ ma, I_{B2} = -0.1\ ma$

The brief summary shown is condensed from very comprehensive tentative military specifications, since the 3N35 has been designed to meet all the requirements of MIL-T-19500/A for electrical, mechanical, and environmental tests.

Collector dissipation is rated at 125 *mw* maximum for a junction temperature of 25°C and derated from that point to zero dissipation at the maximum temperature of 150°C, using a thermal resistance coefficient of 1.0°C/*mw*. Collector breakdown is rated at 30 volts minimum in the more critical but more useful collector to emitter connection.

The chart shows the most important room temperature parameters and their specified maximum or minimum values. Of particular interest are the 70 megacycle parameters shown, which completely define the high frequency performance of the device at the chosen operating point.

The guarantee of a minimum value of power gain by specification of basic parameters is possible mainly

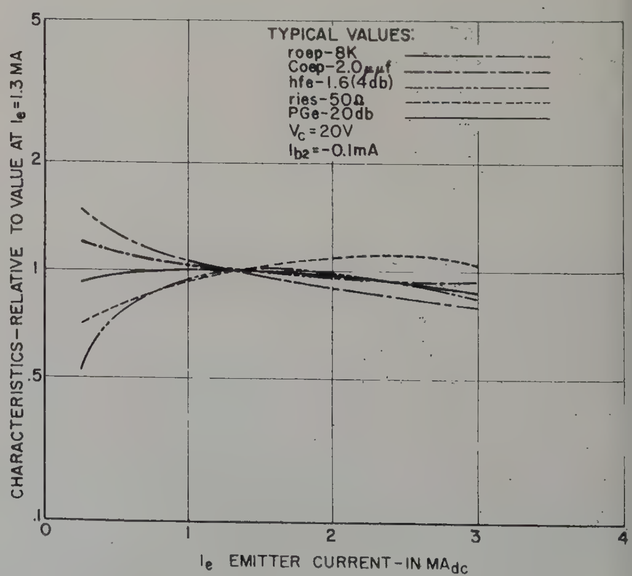


Fig. 16—70 mc characteristics versus emitter current.

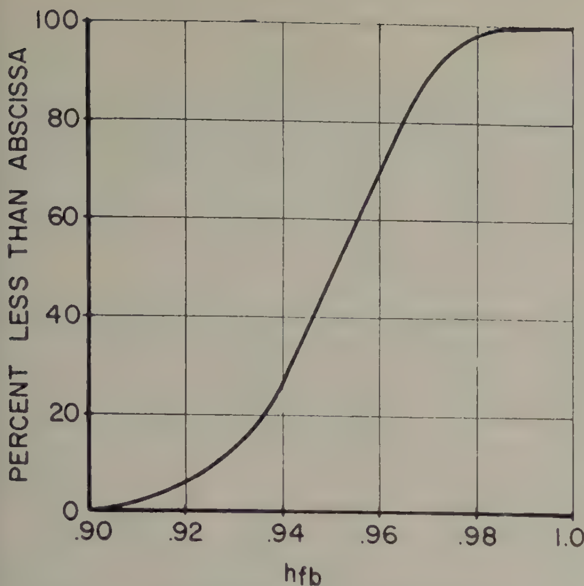


Fig. 14—Distribution of low frequency h_{fb}.

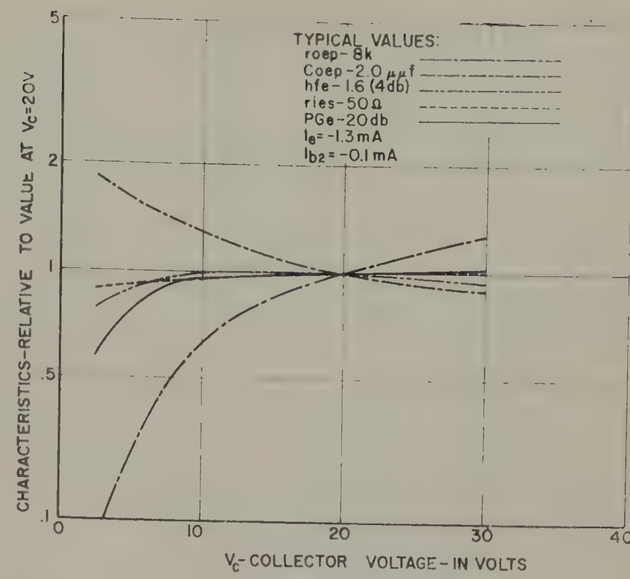


Fig. 15—70 mc characteristics versus collector voltage.

because of the remarkable uniformity in the high frequency characteristics of these transistors. *Figs. 8, 9, 10, 11, 12,* and 13 show the 70 megacycle distribution curves for the parameters h_{fe}, r_{ies}, r_{oep}, c_{oep}, noise figure, and power gain, measured on typical pilot production transistors. Alpha-cutoff frequencies corresponding very roughly to the pertinent h_{fe} values are 100 megacycles at 0 *db* minimum and 150 megacycles for the design center of 4 *db*. Some of the better units have equivalent alpha-cutoff frequencies of 300 to 400 megacycles. It will be noted that a large percentage of the units fall within very narrow parameter limits, considering the difficulty of controlling the fabrication processes and dimensions. *Fig. 14* is the distribution of low frequency alpha, h_{fb}, and here it is seen that even with the reduction in alpha produced by tetrode operation, approximately 80% of the transistors have values of alpha between 0.94 and 0.98, or a beta spread of only 3 to 1.

The 3N35 transistor is relatively insensitive to variation in operating bias conditions. Individual high frequency parameters plus power gain have been plotted against collector voltage in *Fig. 15*, emitter current in *Fig. 16*, and base 2 current in *Fig. 17*. The flatness of the curves in the vicinity of the normal operating point is noticeable, particularly for power gain.

The 3N35 transistor is rated for reliable operation at junction temperatures up to 150°C, and has satisfactorily passed storage and operation tests at this elevated temperature. *Fig. 18* illustrates the variation of measured 70 megacycles power gain with temperature for typical transistors. A 4 to 5 *db* decrease in

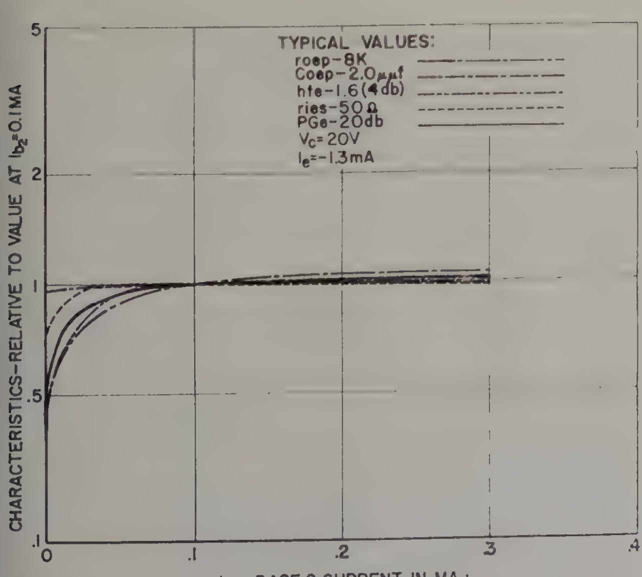


Fig. 17—70 mc characteristics versus base 2 current.

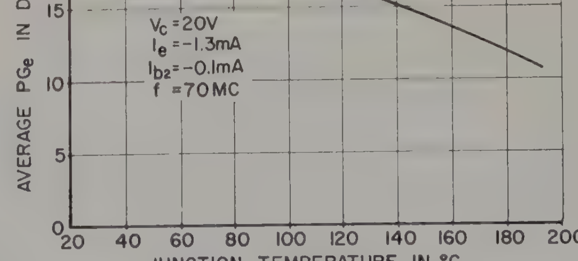


Fig. 18—Variation of power gain with temperature.

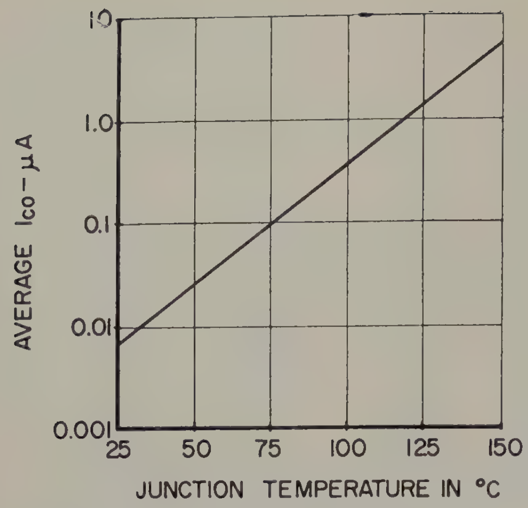


Fig. 19—Variation of I_{co} with temperature.

power gain from room temperature to 150°C may be expected. Variation of I_{co} with temperature is presented in *Fig. 19* for a collector to base voltage of 20 volts.

In reviewing the data presented on measured parameters of typical transistors and the way in which these parameters influence high frequency performance, it is interesting to consider the minimum number of measurements required on each transistor, on a production basis, in order to adequately define satisfactory high frequency performance. If the device design is sound and if conventional *d-c* and low frequency screening tests have first been performed, then the data shows that 3N35 transistors fabricated by a manufacturing process under close control may be adequately specified at some frequency by measurement of the three high frequency parameters h_{fe}, r_{ies}, and r_{oep}. When the proper upper and lower acceptance limits have been determined and specified, other parameters of interest such as power gain, output capacitance, and noise figure will be held within close limits as well and need only be checked on a sampling basis.

CONCLUSIONS

The 3N35 silicon tetrode transistor exhibits extremely good high frequency characteristics which also show a high degree of uniformity. A typical application has been the very satisfactory operation of a transistorized FM receiver using 3N35 transistors in the *r-f* oscillator, and mixer stages. This is a commercially available transistor whose properties of high power gain, stability, and interchangeability make it particularly suited for amplifier operation in the *v-h-f* region. Portions of the work described in this paper were supported by the Signal Corps under Industrial Preparedness Study Contract Number DA-36-039-SC-72703.

Appendix A

The derivation of the high frequency power gain relation shown in Equation (1) starts with two basic relations. If the four-pole transistor parameters are expressed as admittance parameters:

$$\begin{pmatrix} i_1 \\ i_2 \end{pmatrix} = \begin{pmatrix} y_i & y_r \\ y_f & y_o \end{pmatrix} \begin{pmatrix} v_1 \\ v_2 \end{pmatrix} \tag{1}$$

With admittance neutralization, a second two-part network is added to the transistor:

$$y = \begin{pmatrix} y_n & -y_n \\ -y_n & y_n \end{pmatrix} \tag{2}$$

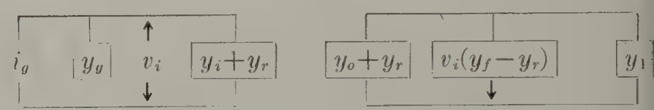
Such that

$$y_n = y_r \tag{3}$$

The combined matrix of transistor plus neutralizing network is:

$$\begin{pmatrix} i_1' \\ i_2' \end{pmatrix} = \begin{pmatrix} y_i + y_r & o \\ y_f - y_r & y_o + y_r \end{pmatrix} \begin{pmatrix} v_1 \\ v_2 \end{pmatrix} \tag{4}$$

In terms of admittance parameters, the transistor with neutralizing network can be represented thus:



For conjugate matched input and output:

$$P_{in} = \frac{|i_g|^2}{4(y_i + y_r)^R}$$

Where the superscript "R" represents the real part of the complex expression.

$$P_o = \frac{|(y_f - y_r)\, v_i|^2}{4(y_o + y_r)^R}$$

$$A_p = \frac{4|(y_f - y_r)\, v_i|^2\, (y_i + y_r)^R}{4(y_o + y_r)\, i_g^2}$$

$$\text{Since } v_i = \frac{i_g}{2\,(y_i + y_r)^R}$$

$$A_p = \frac{|y_f - y_r|^2}{4\,(y_i + y_r)^R (y_o + y_r)^R}$$

$$\text{Defining } h_f = \frac{y_f - y_r}{y_i + y_r}$$

$$h_i = \left(\frac{1}{y_i + y_r}\right).$$

$$y_o'^R = (y_o + y_r)^R$$

Then the power gain relation may be expressed:

$$A_p = \frac{|h'_f|^2}{4\, y_o'^R \quad h_i'^R}$$

If an approximation is made that:

$$y_r << y_i$$

The power gain relation becomes:

$$A_p \doteq \frac{|h_f + h_r|^2}{4\, h_i^R\, (y_o + y_r)^R}$$

Two more approximations can be made which enable more general use of the power gain expression. These approximations have not been made indiscriminately and have been verified at the frequencies of interest by establishment of correlation between calculated and measured power gains.

$$h_r < h_f$$
$$y_r^R < y_o^R$$

With these two approximations the power gain formula reduces to:

$$A_p \doteq \frac{|h_f|^2}{4\, h_i^R\, y_o^R}$$

All Transistor Portable Television

DOUGLAS W. TAYLOR*

This article summarizes the problems arising in the design of the various sections of a transistorized TV receiver. In like manner, the approaches to these design problems are given. As indicated by the author, specific details of the system cannot presently be released. However, they will be made available and published at the earliest possible moment.

THE DEVELOPMENT of the first, all transistor, battery operated television receiver to be publicly demonstrated depended upon the development of adequate transistors for certain critical applications. While transistors have been directly applicable in most television circuit functions for some time, the functions of *r-f* amplifier, video output amplifier and horizontal scan output have not been amenable to transistorization. Recent developments in the transistor art, however, have produced new devices capable of providing excellent results as *r-f* and video amplifiers. The horizontal scan limitation itself has been overcome by a new magnetic lens device which reduces horizontal scan requirements to a level consistent with the capabilities of currently available transistor types. The new receiver utilizing these advances now provides performance specifications comparable to those encountered with tube type receivers.

The receiver uses 31 transistors of which 29 are *p-n-p* types. The picture is displayed on an essentially unmodified fourteen inch, ninety degree picture tube operated at 10 *KV* second anode potential. Power is supplied by a twelve volt, nickel-cadmium, rechargeable battery. The total receiver power consumption of ten watts can be supplied from the batteries for a six hour period before recharging is required. All *vhf* channels are available through a four-wafer, incremental inductance tuner.

Several transistor types have been successfully adapted to the *r-f* amplifier function, including drift and tetrode types, although the new MADT types have thus far provided the best noise figures and approach the performance of tube pentodes in this respect. The rather low gain figures for the single

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r-f stage operating at the upper end of the *v-h-f* spectrum have necessitated the provision of rather high *i-f* gains in order that the diode second detector may operate over a distortion-free range. The cascading of *r-f* stages, while possible, was avoided for practical reasons. The transistor mixer was chosen in preference to the diode type because of its additional gain, while the transistor oscillator operates below signal frequency on the high band in order to assure sufficient injection to the mixer.

The high peak voltage required for the modulation of kinescope beam current places severe restrictions upon the minimum collector-base breakdown voltage rating of the video output transistor. Further, this unit must be capable of dissipating considerable power because of the necessarily low value of resistive load at the required 3.5 *mc* bandwidth. Several of the newest drift types meet both of these requirements as well as having adequately high alpha cutoff values.

The horizontal scan provision in a transistorized receiver is probably the most difficult problem of all and is one for which no really adequate transistor yet exists. To provide wide angle scan at high ultor potentials requires a device capable of switching a large value of reactive power within a fraction of a microsecond. Should the switching time be longer than this, large amounts of the circulating power in the system will, of necessity, be dissipated in the collector of the switching transistor. While the reactive power may be presented to the switch with any desired ratio of current to voltage, the peak voltage swing will normally be set at the maximum safe collector rating. The mode of circuit operation can be modified, as in this receiver, so as to minimize the switching time requirement although the basic limitations still exist and, as yet, no available transistor type is satisfactory. Further, should an adequate transistor become available, it is questionable if the fixed losses of the system itself can reasonably be supplied from batteries of usable dimensions. This seeming impasse has been surmounted by a scan magnifier which reduces the required circulating power and makes several production type transistors equal to the requirements. While the details of the system cannot presently be released, the author will publish on this subject at the earliest possible moment.

With systems involving large amounts of circulating power in the horizontal scan output, high voltage is usually derived as a by-product of this power. Since no large amounts of power are involved in the horizontal scan system, a separate high voltage system has been designed to operate at maximum efficiency within the limitations imposed by the transistor involved. The high voltage output transistor, a common power type, is operated as a switch and is keyed by the horizontal scan system. Sufficient drive is presented to the base of the transistor to ensure bottoming and minimum switching time. The switching duty cycle is 50% so that a symmetrical square wave of voltage is presented to the transformer which is approximately resonant at the switching repetition rate. Operation at this low transformer resonance of 15,750 *cps* rather than the 150 *kc* resonance required by combination scan and high voltage transformers allows the transistor switching time to be several micro-seconds without introducing unreasonable losses in the switch itself. As a result, system efficiencies in excess of 70% have been obtained including the losses in the silicon rectifier voltage quadrupler section. The output of 10,000 volts at 300 μ*amp* or better is available at a source impedance of approximately six megohms.

The *i-f* amplifier must, as previously noted, provide excess gain as compared to its tube counterpart. In typical six stage units, gains in excess of 100 *db* are achieved at 45 *mc* with a 6 *db* bandwidth of 3.5 *mc*. The necessity of providing automatic gain control in a television *i-f* amplifier has led to the adoption of tetrode transistors in the first four stages since these are the only types capable of controlled gain variation without excessive change in overall frequency response. A *p-n-p/n-p-n* transistor *d-c* amplifier is used in the *a-g-c* feedback loop to provide the required driving characteristic for the tetrode second bases. Matched bandwidth conditions obtain for all stages at maximum gain and the chain of stages is approximately isochronously tuned so that with the bandwidth shrinkage over six single tuned stages, the total bandwidth is equal to the required 3.5 *mc* value. Double tuned, neutralized amplifiers as well as degenerative *a-g-c*, and all triode amplifiers are currently being investigated for subsequent receiver versions.

The sound system is straightforward and has presented no unusual problems. A locked oscillator FM detector shows some promise and may replace the conventional ratio detector affording further economies in this section.

Transistors are ideally suited to the task of sync separation and vertical scan production so that a multitude of commercial types are quite suitable for these applications. The vertical scan output section is somewhat unusual in that it is a direct coupled, push-pull system. The *d-c* component of collector current in the yoke is effectively cancelled by this system and low power transistor types can be utilized because of the scan magnifier device. A balancing provision must be made for the push-pull section to compensate for unit to unit variation in transistor characteristics.

Finally, the introduction of this receiver can only be termed inevitable in view of the rapid improvement in the transistor art. Continued progress in the art, coupled with refinement of application, must soon lead to the commercial introduction of truly portable television receivers. Such an innovation will be of greatest significance for both the transistor and television industries.

The Effect of Base Resistivity on Power Transistor Performance

BERNARD REICH*

Starting with the variation of resistivity of impure germanium with temperature, the author develops its effect on device characteristics and circuit performance.

RECENTLY an investigation was made into the operation of germanium alloy power transistors, as audio amplifiers, under varying conditions of junction temperature. It was found that all power transistors observed did not exhibit identical temperature characteristics. However, the temperature performance of a particular manufacturer's type exhibited an inherent characteristic of its own. For example, the current gain of manufacturer A's transistor exhibited a tendency to decrease monotonically above +40°C. Manufacturer B's unit exhibited an increasing current gain from 25°C-65°C and then above this temperature a rapid decrease, and so on. Some conclusions were drawn from these preliminary experiments:

1. In addition to the normal production variables affecting the current gain magnitude at a particular bias point and measurement temperature, the dependence of this parameter as a function of operating junction temperature must be considered.

2. Matching transistors at a particular operating temperature does not guarantee similar results at other operational temperatures. This includes matching combinations of *p–n–p/p–n–p* and *p–n–p/n–p–n*.

The results of this study prompted the author to investigate the variation of current gain as a function of junction temperature analytically.[1] The analysis indicated that at high injection levels where the emitter efficiency limits the current gain of a transistor, the base resistivity governed the shape of the gain-temperature curve. With this background in mind some attention will now be directed to the effect of base resistivity on the current gain-temperature characteristic of germanium power transistors.

Base Resistivity Effect on Current Gain.

The resistivity of both *n* and *p*-type germanium vary with temperature. *Figs. 1* and *2* are plots of the variation of *n* and *p*-type germanium over the temperature range 25-100°C. These curves are the results of calculations made by P. G. Herkart and J. Kurshan.[2]. The curves presented are generally indicative of the range of resistivity of base material used in fabricating most homogeneous base devices. It is noted from these curves that the more highly doped the germanium, indicated by lower resistivity, the less temperature variation is noted. From the point of view of designing a temperature-stable transistor, low resistivity material would be most suitable. However other considerations such as breakdown voltage may delegate operating at higher resistivities.

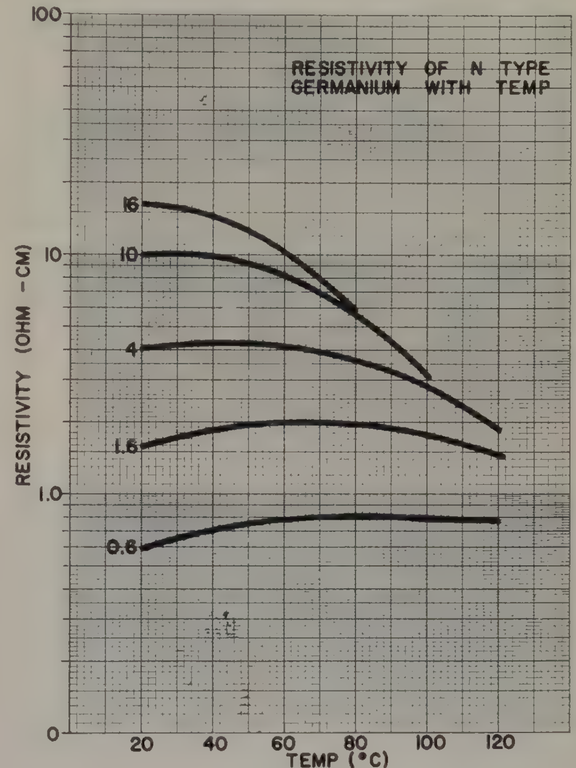

Fig. 1—Resistivity of *n*-type Ge with T.

Keeping in mind the preceding discussion of the variation of resistivity with temperature, attention will be directed to the application of this information to fabricated devices. The author was able to locate devices with different base resistivities. Other fabrication details of the devices were identical. The units

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Fort Monmouth, New Jersey

[1] *Temperature Sensitivity of Current Gain in Transistors—B. Reich—to be published in the TRANS IRE, PGED APRIL 1958.*

[2] *Theoretical Resistivity and Hall Coefficient of Impure Germanium Near Room Temperature—P. G. Herkart and J. Kurshan—RCA Review, Vol. XIV, Sept. 1953.*

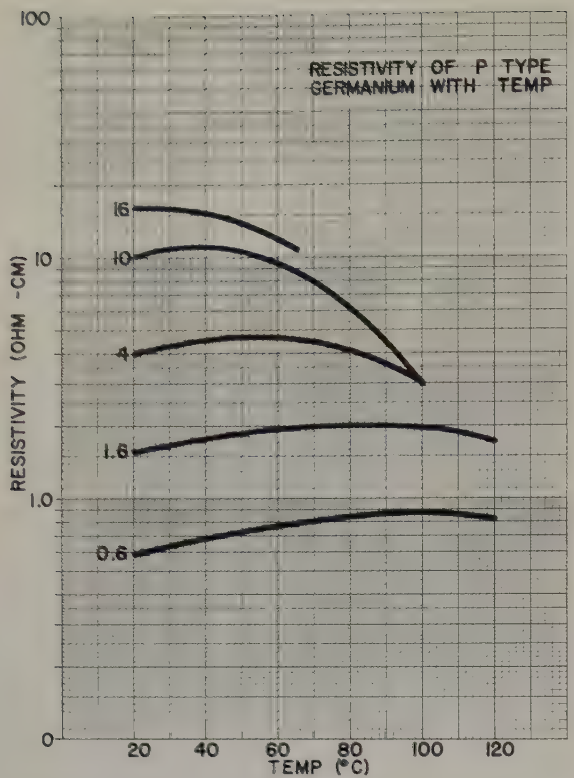

Fig. 2—Resistivity of p-type Ge with T.

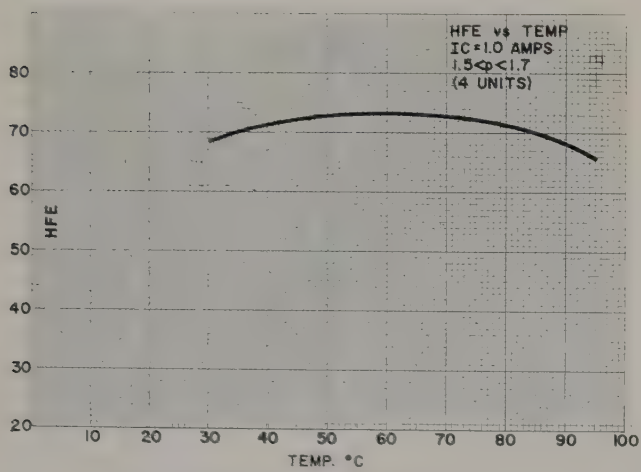

Fig. 3—HFE vs T. (1.5-1.7 ohm-cm)

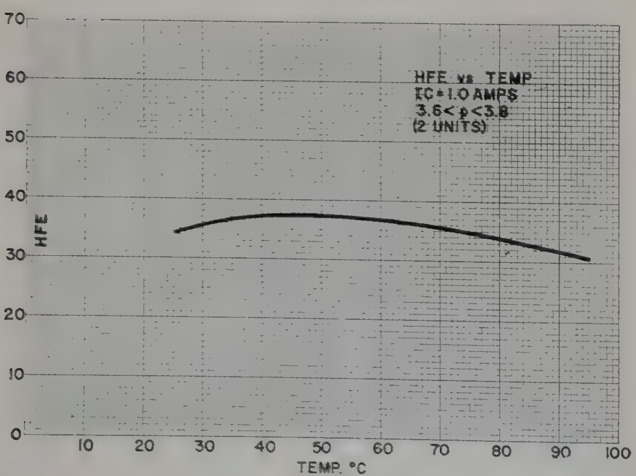

Fig. 4—HFE vs T. (3.6-3.8 ohm-cm)

investigated were power transistors fabricated with gallium-indium emitters and indium collectors.

Current gain-temperature curves were run between 30°C and 95°C at a collector bias of one ampere. *Fig. 3* is such a plot on units fabricated from germanium with a range of resistivity between 1.5-1.7 ohm-*cm*. The curve represents the average of four units measured. Particular emphasis is directed to the shape of this curve. It should be noted that the gain increases initially with temperature and begins decreasing above 70°C. This is quite similar in shape to the 1.6 ohm-*cm* curve of *n*-type germanium shown in *Fig. 1*. For the purposes of this analysis, the magnitude of gain is not considered important because of inherent processing variations. *Fig. 4* is a plot similar to *Fig. 3* except that the units were fabricated from germanium having a resistivity between 3.6 and 3.8 ohm-*cm*. Attention is directed to the increasing initial characteristic and fall off above approximately 50°C. This is in good agreement with the 4 ohm-*cm* curve of *Fig. 1*. *Fig. 5* is a plot of the gain temperature characteristic of units fabricated from 5.7-7.0 ohm-*cm* material. Fall off above 35° to 40°C is noted. The curves seem to follow, to fairly good agreement, the base resistivity temperature variation.

It is evident from these curves that for the best current gain response over the temperature range indicated, low resistivity material is most ideal. However most manufacturers, in their efforts to produce satisfactory breakdown voltage characteristics, will go to higher resistivity material. To illustrate this, a calculation of the collector diode breakdown voltages will be made of the three different resistivity units illustrated in *Figs. 3, 4,* and 5. Using the expression stated by Messenger[3]

$$V_D = C_7 \rho_b{}^k \tag{1}$$

where V_D is the diode breakdown voltage,
C_7 is an empirical constant in this case 32,
ρ_b is the base resistivity,
and K is another empirical constant equal to ½.

The diode voltages are calculated to be 40, 62 and 81 volts respectively for the 1.6, 3.7 and 6.35 ohm-*cm* nominal base resistivities.

Power Transistor Performance.

The concluding section of this paper is really the information which sparked the investigation presented previously. In the preceding sections, the effect of bulk resistivity of the base material on the current gain has been presented. What does this mean to the engineer designing an audio amplifier? In this section of the report information will be presented on the variation of current gain with temperature of two particular types of power transistors and the resultant effect on performance. *Fig. 6* is the circuit diagram of

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[3] *Transistor Design Equations—G. C. Messenger—Philco Corp., Philadelphia, Pa. (Personal Communication).*

a Class A audio amplifier in which the performance of two particular power transistor types, readily available for purchase at the time of the investigation, is shown. The devices were obtained from two different manufacturers and will be designated as Type A and Type B for the remainder of this report. They were *p-n-p* types, fabricated with gallium-indium emitters and indium collectors, however, the Type A unit was fabricated with higher resistivity base material than Type B.

The measurements of power gain with increasing temperature were made under the following conditions:

1. Test Frequency—1000 cycles/*sec*
2. Collector Bias Current—0.5 amperes
3. Collector Voltage—6 volts
4. *A-C* Input Voltage—200 *mv*.

Figure 7 is a plot of the current gain and power gain of a typical Type A transistor. The *d-c* current gain represented was measured at the 0.5 ampere biasing point. It is noted that the current gain begins falling off above 40°C and decreases monotonically above this point. While the actual current gain shown in *Fig.* 7 is measured at 20°C and above it is noted that measurements of power gain begin at 35°C. This can be explained by the fact that the abscissa represents the operating junction temperature. Calculations were made, taking into account the dissipated power during the measurements, and the thermal resistance of the transistor. These latter remarks also apply to the Type B unit which will be discussed shortly. It is noted from *Fig.* 7 that the power gain variation with temperature follows closely the current gain variation.

Examination of *Fig.* 8 indicates a flat current gain-temperature response with a similar power gain response of the type B unit. The resultant information on both types of units indicates that varying resistivity of the base material in transistors will vary the current gain and power gain response with temperature, characteristics which may be entirely overlooked by the device designer in his effort to increase breakdown voltage.

Conclusions.

In his attempt to increase breakdown voltage in power transistors, the device designer may overlook the consequences. This report indicates that resistivity of the base material plays heavily in the temperature characteristics of power transistors. Lower resistivity material will result in devices having better temperature stable parameters. This, in turn, will result in better temperature performance in circuits.

ACKNOWLEDGMENTS.

Acknowledgment is made of the efforts of Mr. Sheldon Stern and Mr. Charles McAfee, Solid State Devices Branch, for the measurement results reported.

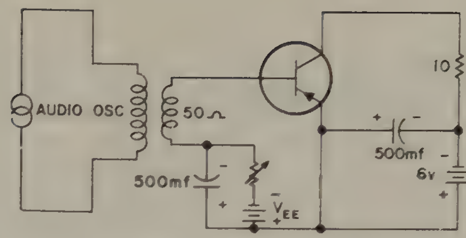

Fig. 6—Audio oscillator test circuit.

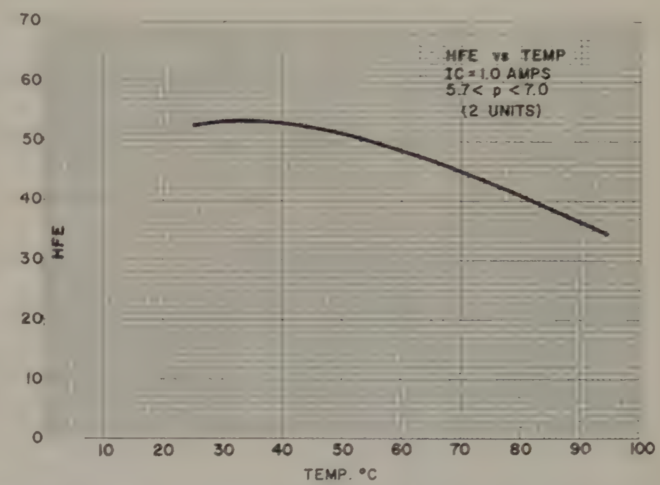

Fig. 5—HFE vs T (5.7-7.0 ohm-cm).

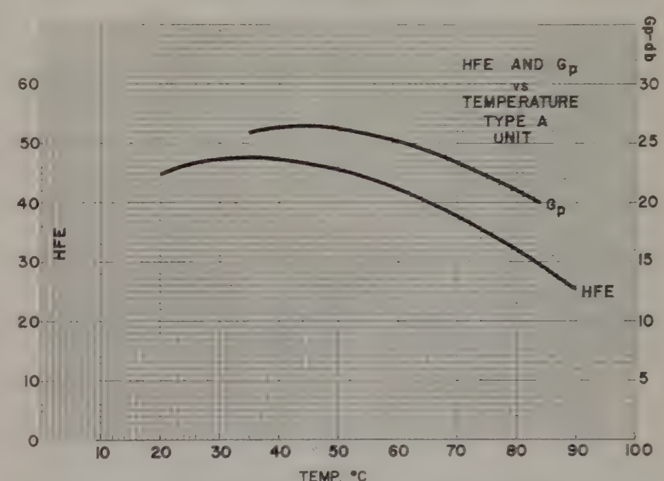

Fig. 7—HFE and G_p vs T (type A unit).

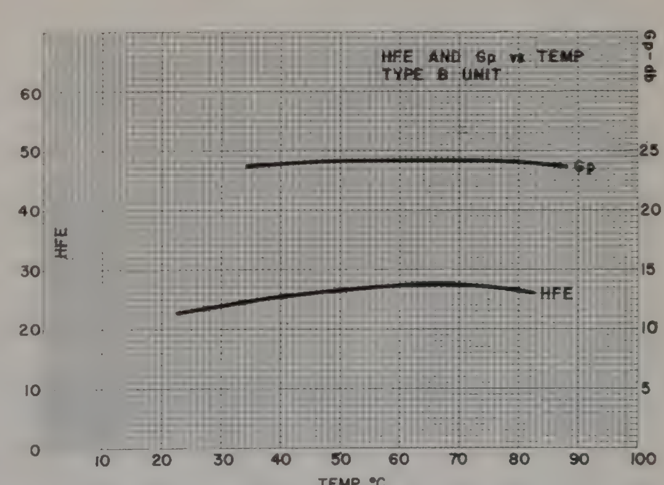

Fig. 8—HFE and G_p vs T (type B unit).

Semiconductor Diode Test Methods

W. B. MITCHELL* and J. GILLETTE*

Semiconductor diode characteristics are presented and representative circuits are shown to measure these characteristics. Circuits are included for measuring the static, dynamic, and operational characteristics. Other circuits may be used in place of the ones chosen; but in general the ones selected are in most common use throughout the industry.

IN ORDER to successfully evaluate a semiconductor diode, it is first necessary to decide which characteristics are important and what circuits will be used to measure these characteristics. Only a few years ago the number of different types of diodes was about one hundred, and users of semiconductors "knew" these types. But now the total is well into the thousands and no one person can be familiar with all the individual characteristics of all the different types. For this reason it is essential that we be able to specify the necessary diode parameters and that we have circuits capable of accurately measuring them. This article will present a brief description of the major characteristics of semiconductor diodes and typical circuits used in their measurement.

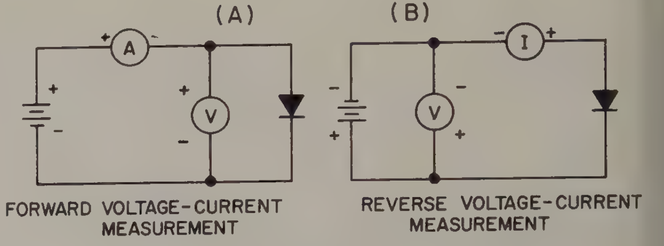

Fig. 1—Direct current measurements.

Forward Characteristic

The forward, or conducting, characteristic of a semiconductor at low current is generally given by the equation

$$I = I_s \left[exp \left(\frac{qV}{kTC} \right) - 1 \right] \tag{1}$$

where

- I is the current through the diode
- I_s is the saturation current
- q is the electron charge
- V is the voltage across the junction
- k is Boltzman's constant
- T is the junction temperature in °K
- C is a factor which ranges from 1 to 2 depending on the forward current

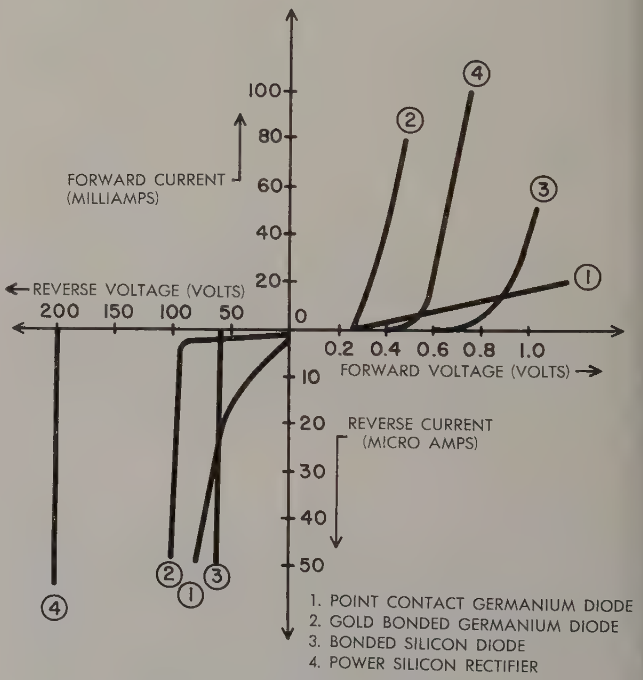

Fig. 2—Diode static characteristics.

The saturation current, I_s, is a function of the semiconductor material, the junction area and type, and the temperature. For a given diode, over the operating temperature range, the saturation current will approximately double for each 10°C increase of temperature. Typical saturation currents for small signal germanium diodes run around 10^{-7} amperes and for small signal silicon diodes around 10^{-13} amperes.

The forward V-I characteristic is generally measured by a simple volt-ampere method as shown in *Fig. 1A*.

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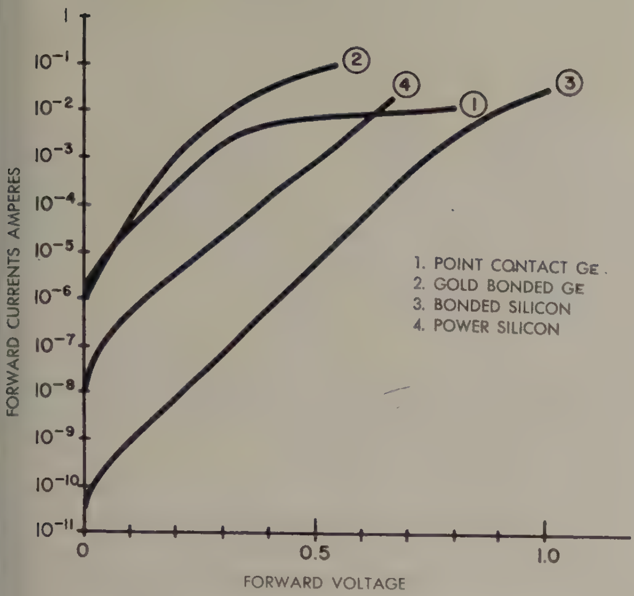


Fig. 3—Diode forward dc characteristics.

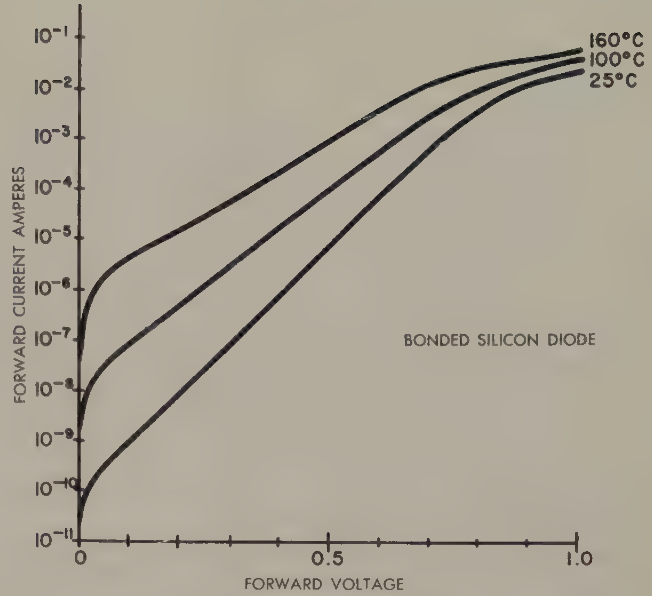


Fig. 4—Diode dc forward characteristics as a function of temperature.

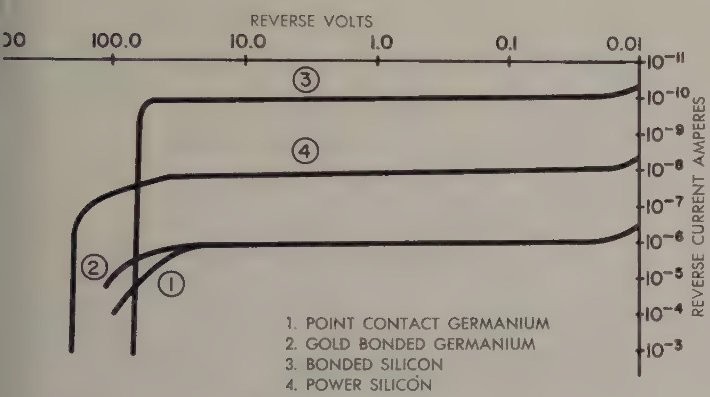


Fig. 5—Diode reverse dc characteristics.

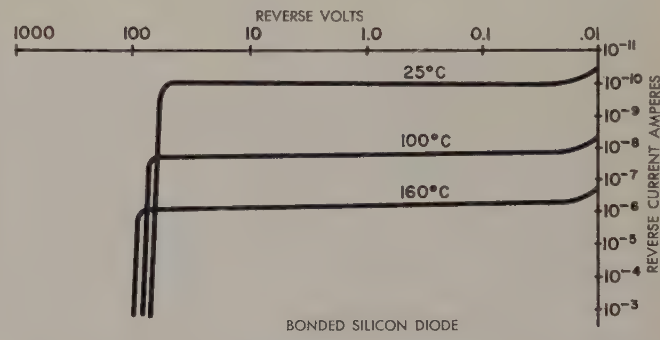


Fig. 6—Diode reverse voltage—current dc characteristics as a funtion of temperature.

There are two points to be aware of when using this circuit. The first is that when the diode is drawing large currents, the voltmeter should be connected directly across the diode so that there is no voltage drop due to resistance of the connecting wires. The other problem occurs when the diode is conducting very small currents. In this case the voltmeter must have a very high impedance, and in some cases must be an electrometer.

Figure 2 gives typical curves of the forward V-I characteristics of different types of semiconductor diodes measured in circuit 1A at 25°C.

In *Fig. 2* there appears to be a break point or threshold in the curves. Actually there is no discontinuity, but appears so due to the fact that the current is increasing exponentially. To illustrate this, the same curves are plotted on semilog scales in *Fig. 3*.

By comparing *Fig. 3* with *Fig. 2*, it will be noticed that there is no longer a discontinuity at the threshold which appears in *Fig. 2*. The curves deviate from a straight line at higher current levels because the measured voltage does not all occur across the junction but partly across the internal ohmic resistance of the diode.

Since *Eq. 1* contains "T" in the exponent, and because the saturation current is also a function of temperature, it is natural to expect the forward characteristic to vary with temperature. *Fig. 4* shows curves of a type 1N300, bonded silicon diode at various junction temperatures. The saturation current, I_s, can be obtained by extending the straight line portion of the curves until it intersects the vertical, or $V = O$, axis.

Reverse Characteristic

If in *Eq. 1* the voltage, V, becomes negative, then the term $\exp qV/kT$ goes to zero very rapidly. (At —0.1 volt it is less than 0.02 and at —0.2 volts it is less than 0.0004.) Thus the reverse current should be constant at I_s for any voltage above a few tenths of a volt or so. In actual measurements, however, it appears

that this is not so, but that there is a multiplication factor which is a function of the applied voltage. There is also a shunt resistance (leakage) due to contamination of the junction surface. At some large reverse voltage there is an avalanche breakdown at which point the diode conducts heavily. This is often referred to as the Peak Inverse Voltage, or P.I.V. of the diode.

Figure 1B shows the circuit used to measure the reverse characteristic of a diode. The circuit of *Fig. 1A* could be used if the voltmeter current were much less than the diode current, but in general, the few millivolts drop across the ammeter will be insignificant.

Figure 2 shows the reverse characteristics of the same diodes measured at 25°C. The same curves are plotted on log paper in *Fig. 5*.

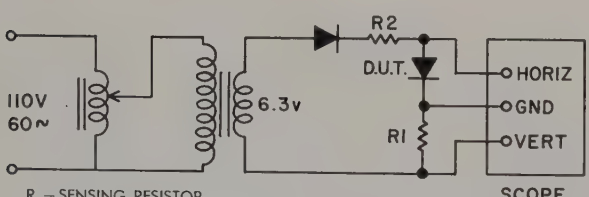
Figure 6 shows the reverse characteristic of the bonded silicon diode of *Fig. 2* plotted at various temperatures.

The shift of reverse breakdown with temperature is common with this type of diode. A variation of about 0.1% per °C to 0.2% per °C is typical. Thus a reverse voltage safety factor must be applied for low temperature operation.

Dynamic Presentation

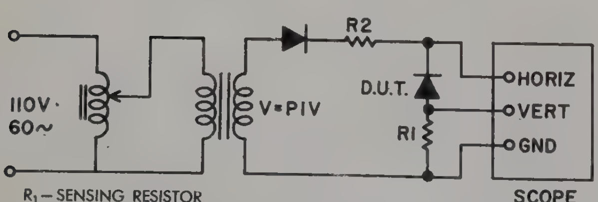
At times it is desirable to have a dynamic presentation of the V-I characteristics. *Fig. 7* shows a typical circuit used to provide a forward dynamic presentation, and *Fig. 8* a circuit for the reverse.

This method is particularly valuable when the measurement to be made is at a value to cause the diode to overheat. For example, values of either forward or reverse current can be obtained at higher levels since the high current is applied only for a short time and the heating is less than if there was a direct current.



R_1 – SENSING RESISTOR
R_2 – LIMITING RESISTOR
D.U.T. – DIODE UNDER TEST

Fig. 7—Forward dynamic presentation.



R_1 – SENSING RESISTOR
R_2 – LIMITING RESISTOR
D.U.T. – DIODE UNDER TEST

Fig. 8—Reverse dynamic presentation.

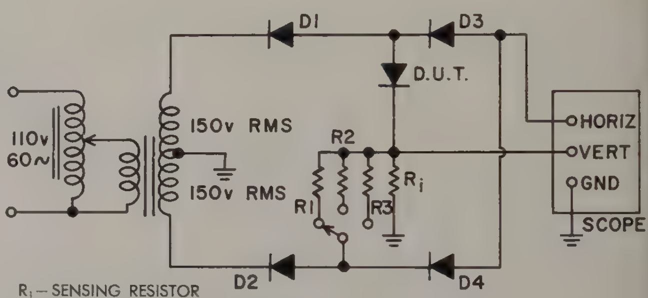
Reverse Resistance

Sometimes for point contact germanium diodes it is required that the reverse resistance be greater than a specified value over a wide voltage range. *Fig. 9* shows the diagram of the circuit which will display simultaneously the reverse V-I curve and a specified resistor.

With this circuit it is easy to compare the diode reverse with a linear resistance. *Fig. 10* shows the presentation of a 1N67 point contact germanium diode and a one megohm resistor.

Operating Test

In some applications it is necessary to know how much reverse current flows through the diode when it is acting as a rectifier. This can be particularly important in magnetic amplifiers. In this case the average reverse current over the half cycle is important. *Fig. 11* gives a circuit for making this measurement. The forward current flows through diode D_1 and is measured on ammeter M_1. The reverse current flows through diode D_2 and is measured on ammeter M_2. This test is generally made with the diode operating at its maximum rated temperature and the maximum forward current allowed at this temperature.



R_i – SENSING RESISTOR
R_1, R_2, R_3 – COMPARISON RESISTORS
D_1, D_2, D_3, D_4 – 300v P.I.V. SILICON DIODES
D.U.T. – DIODE UNDER TEST

Fig. 9—Test circuit for comparing diode reverse characteristics with that of a fixed resistor.

Capacity

The capacity of a semiconductor diode varies with the applied voltage. As the inverse voltage is increased the diode capacity decreases by the following relation:

$$C = C_1 + K_1/(V + K_2)^{1/N} \qquad (2)$$

where

C is the total capacitance

C_1 is the package capacitance

K_1 and K_2 are constants

N is a constant which ranges from 2 to 3 depending on the diode type

V is the applied inverse voltage.

For inverse voltages greater than one volt K_2 may be neglected without introducing appreciable error. Capacity in the forward direction involves storage of minority carriers. This measurement is quite involved and is omitted. Diode capacity is usually measured on a "Q" meter modified as shown in *Fig. 12*.

The circuit, with the diode removed, is resonated at the specified frequency. The "Q" meter capacity is noted. Then, with the diode inserted in the circuit and the specified reverse voltage applied, the circuit is

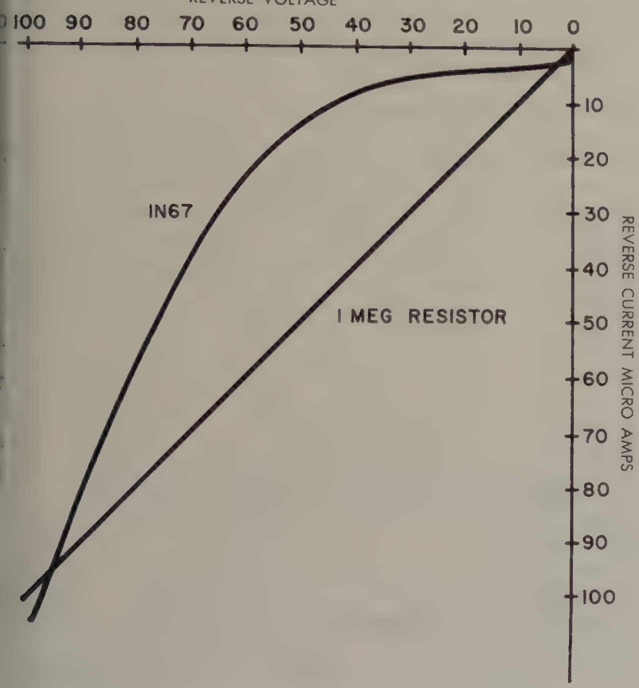


Fig. 10—Diode reverse characteristics compared to that of a fixed resistor.

again resonated by varying the "Q" meter capacity. The diode capacity is the difference in the two capacitor settings. Since diode capacity is a function of voltage, it is necessary to keep the *r-f* voltage across the diode small compared to the *d-c* bias. This is accomplished by keeping the *r-f* drive at a low value. Resistor *R* should be as large as possible without having an appreciable *d-c* voltage drop across it due to the diode reverse current.

Diode capacity versus voltage for various types of diodes is shown in *Fig. 13*. It should be noted that the slope, $1/N$, of the graphs for diffused diodes (a graded junction) is $-1/3$. The other diodes are alloy types (step junctions) and have slopes of $-1/2$.

Forward Transient Response

The forward transient characteristic, commonly called forward pulse recovery, describes how a diode switches from a non-conducting state to a forward conducting state. The forward voltage drop produced by a pulse of current for an ideal recovery diode and a typical computer diode is shown in *Fig. 14*.

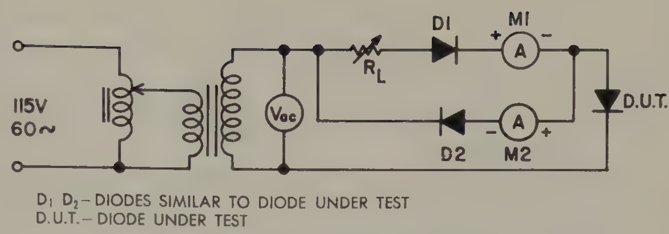


Fig. 11—Diode operating test circuit.

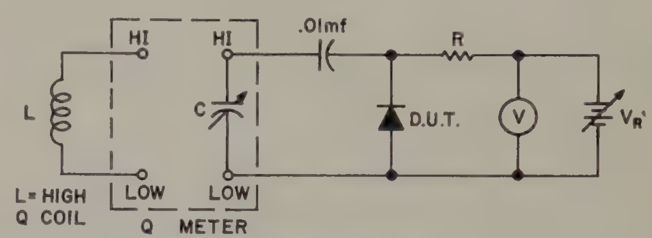


Fig. 12—Capacity measuring circuit.

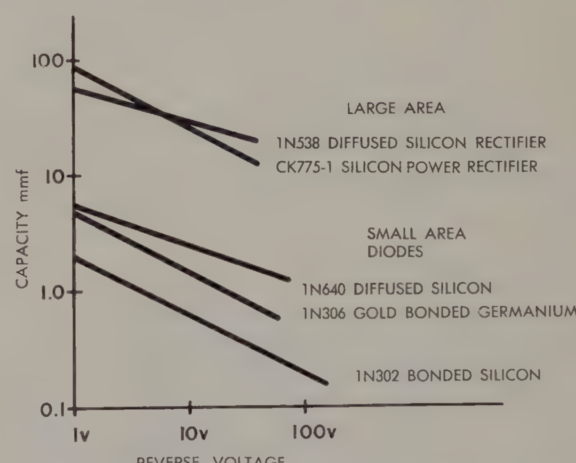


Fig. 13—Capacity characteristics of various diodes.

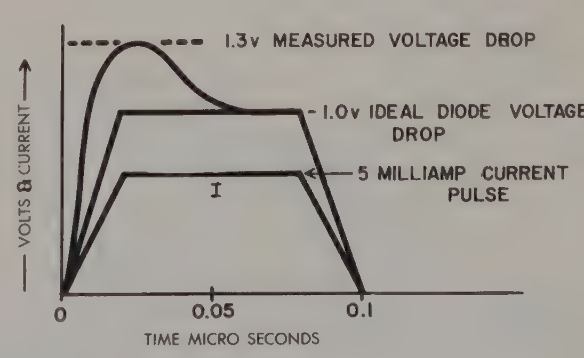


Fig. 14—Response comparison of a typical diode to an ideal forward recovery diode.

Forward pulse recovery is usually specified as a maximum peak voltage drop at a specified time after the application of the specified current pulse. *Fig. 15* shows a simple circuit usually used for making such a measurement.

Forward recovery is very important in high speed logic circuits such as diode gates. If the forward recovery is poor, short pulses may be greatly attenuated.

Inverse Transient Response

The inverse transient characteristic, commonly referred to as inverse pulse recovery, describes how a diode switches from the forward conducting state to the reverse cut-off condition. Unfortunately, diodes are far from ideal switches. The time required for a diode to recover to its high inverse impedance varies with the type of diode and its circuit application.

Assume an ideal diode being driven from 5 *mA* forward to —40 volts reverse by a generator having a finite rise time and a specified impedance. *Fig. 16* depicts the ideally expected current and a typical poor-recovery diode. Immediately after switching, it is observed that the diode reverse current is much larger than the normal leakage current. Transient specifications are usually written as minimum equivalent *d-c* resistance or maximum current at a specified time after switching is initiated. *Fig. 17* shows a JAN 256 reverse transient test circuit. This is but one of many circuits used throughout the industry.

The forward current flows from a variable voltage supply, V_1, through R_1, R_2, and R_3, through the diode

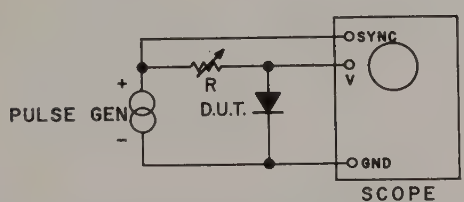


Fig. 15—Forward transient test setup.

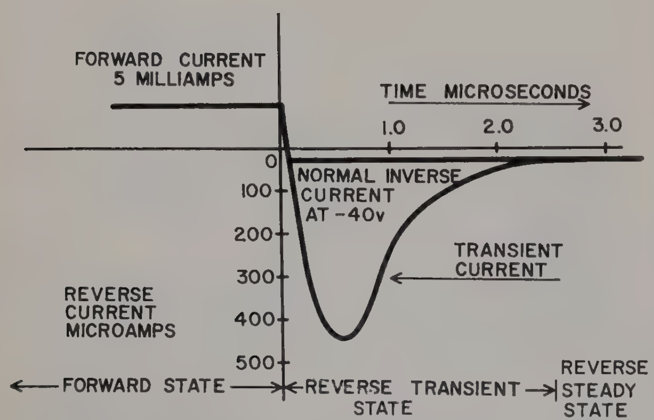


Fig. 16—Response comparison of a typical diode to an ideal reverse recovery diode.

under test and through CR_2. The reverse bias is supplied by the square wave generator. The voltage across R_L is proportional to the switching current and is observed on an oscilloscope. T_1 is a cathode follower to isolate the scope from the test circuit. CR_2 shunts R_L during the forward conduction cycle to limit the maximum positive grid potential on T_1. CR_3, CR_4, CR_5 and CR_6 form part of a safety device to prevent the voltage across the diode test clips from rising to B+ when there is no diode under test.

Figure 18 shows the wide variation of reverse recovery for different types of diodes. *Figs. 19* and *20* show the effect of variations of forward current and reverse voltage on reverse transient response.

Rectification Efficiency

Rectification efficiency is a characteristic which gives a figure of merit for a particular type of operation. Power rectification efficiency is often defined as *d-c* power output divided by *a-c* power input. *Fig. 21* shows a circuit which can be used to make this measurement.

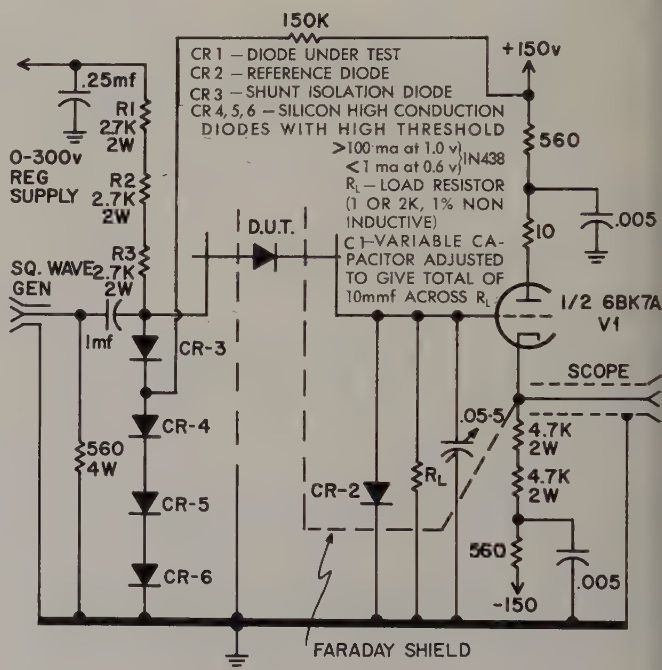


Fig. 17—Modified Jan 256 reverse pulse recovery test circuit.

It is often inconvenient to insert and adjust a wattmeter for each diode tested. Very often the wattmeter is eliminated and the rectification efficiency is defined as the average *d-c*. Load Voltage divided by the *a-c* Peak Input Voltage. For example some military diode specifications require a 35% efficiency when $e_{IN} = 2v$ *rms* at 100 *mc* and R_L is 5000 ohms in parallel with a 20 $\mu\mu f$ capacitor.

For other than power application, high frequency rectification efficiency is difficult to measure, and relative standards based on a particular diode or on a specific circuit are utilized. One such application is

he standard CK706A video detector test. A typical ideo detector circuit is used (*Fig. 22*) and the diode pecification states at a CK706A must produce a minimum *d-c* current of 375 uA through meter M_1.

Dynamic Resistance

In many diode applications it is desirable to know he slope, or dynamic resistance of the diode at a specified current or voltage. *Fig. 23* shows the diagram of the circuit used to measure this characteristic. The *d-c* voltage and current applied to the diode are measured on meter M_1 and M_2 respectively. A small signal

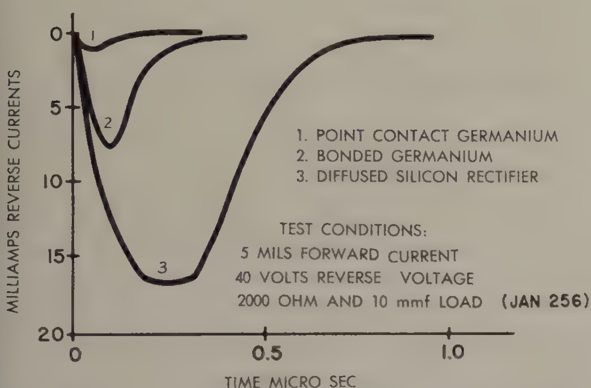


Fig. 18—Reverse pulse for various types of diodes.

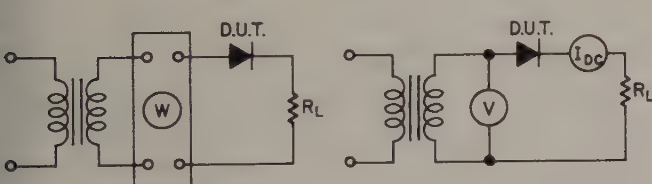


Fig. 21—Power rectification efficiency test.

a-c current is applied to the diode through R_1 and produces an *a-c* voltage across the diode proportional to the dynamic resistance at that value of current and voltage. This circuit is useful in measuring the impedance of the breakdown region of "Zener diodes" and also for checking the forward dynamic resistance. As in all circuits of this type, it is necessary to keep the *a-c* probe current small as compared to the *d-c* current in order not to change the operating point.

Assuming a forward voltage of over a tenth of a volt, the "—1" of *Eq. 1* can be neglected, and differentiating with respect to V gives:

$$\frac{dI}{dV} = \frac{I_s q}{kTC} exp \frac{qV}{kTC} \qquad (3)$$

or

$$\frac{dI}{dV} = \frac{q}{kTC} I$$

$$R_d = dV/dI = \frac{kTC}{q} \Big/ I \qquad (4)$$

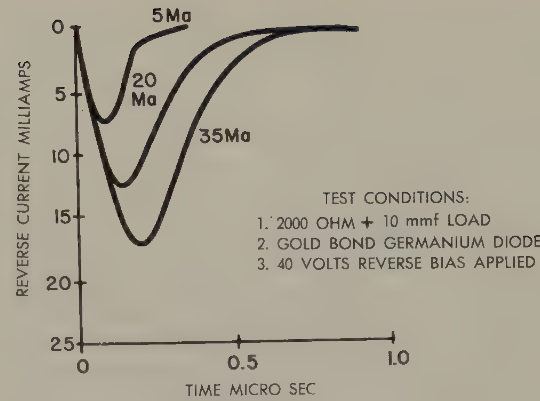


Fig. 19—Effect of forward current on reverse recovery.

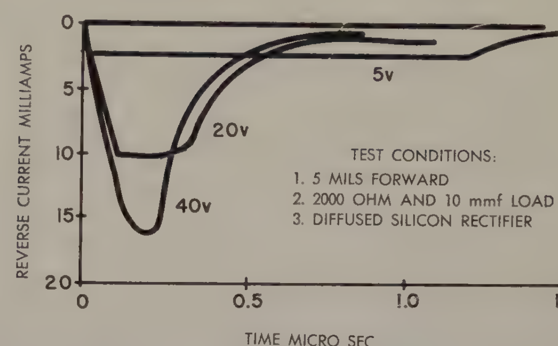


Fig. 20—Effect of reverse voltage on reverse recovery.

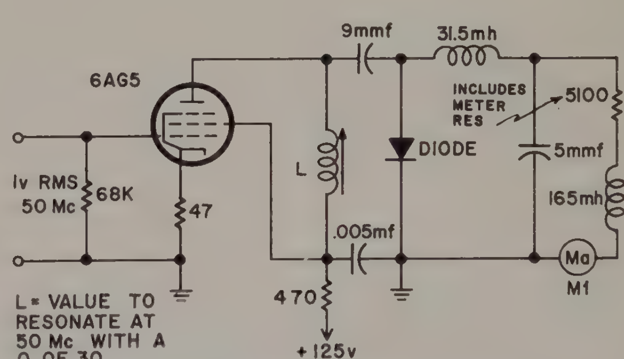


Fig. 22—Video detector test circuit.

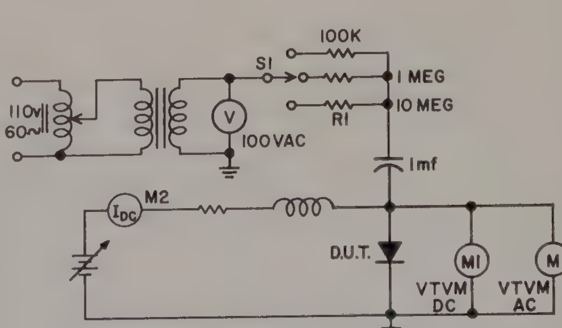


Fig. 23—Diode dynamic resistance measuring circuit.

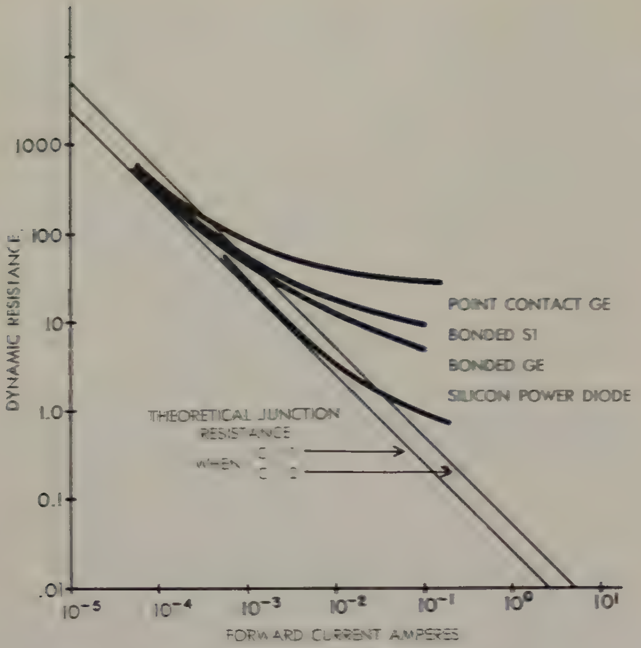


Fig. 24—Forward dynamic *R* of various diode types.

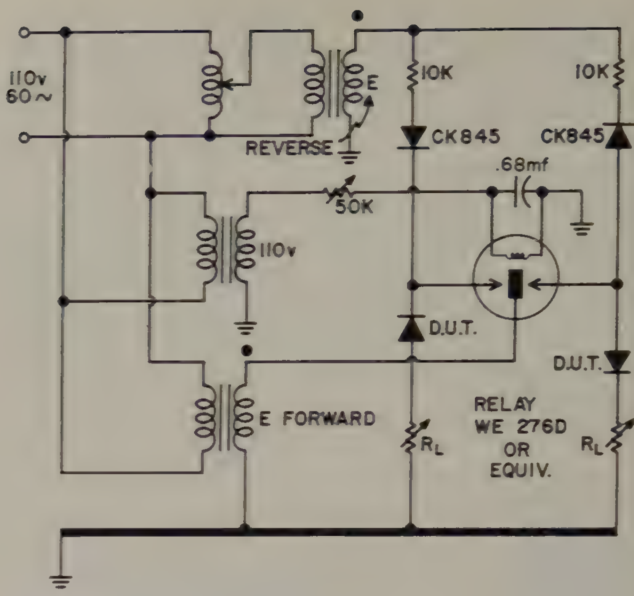


Fig. 25—Life test circuit.

Thus the resistance of the diode junction is proportional to the inverse of the applied *d-c* current. At 25°C kt/q is approximately $C/40$ so at a forward current of one milliampere the junction resistance will be between 25 and 50 ohms.

Figure 24 shows a plot of the forward dynamic resistance of various types of diodes as a function of the *d-c* current. The two straight lines are plots of *Eq. 4* for $C = 1$ and $C = 2$. The difference between the theoretical and actual curves can be attributed to the internal resistance of the diode and the fact that C is a function of I.

Life Tests

In general, diodes are life tested as normal rectifiers, with a specified input *a-c* voltage, and a specified load resistor. In low current diodes this is perfectly acceptable, but in higher current diodes, there is considerable heat dissipated in the load and this is quite often prohibitive. For example, a diode carrying one ampere with a peak input voltage of 600 volts would require 470 watts to be dissipated in the load resistor while only about 1 watt would be dissipated in the diode. There have been many attempts to get around this problem, but for currents up to 5 amperes, the circuit of *Fig. 25* has proved to operate very well.

Conclusion

Although the above tests are by no means the only ones which can be made on a semiconductor diode, they are by far the most common, and generally evaluate the majority of diodes adequately. Often, though, some of the test circuits are modified and revised for special applications, in general, test results on one type of equipment may be correlated with measurements made on others. As with other components, however, a semiconductor diode is only as good as the equipment in which it is measured.

Electrical Breakdown in P-N Junctions†

A. G. CHYNOWETH*

In semiconductor devices, p-n junctions can "break down," or permit a sudden flow of electricity in the direction that normally shows high resistance. For some time a puzzle to physicists, the mechanism of this phenomenon can now be described as a result of recent research studies carried out at Bell Telephone Laboratories.

PURE CRYSTALS of silicon or germanium are relatively poor electrical conductors at room temperature, but their conductivity can be increased by deliberately adding certain impurities to them. Impurities with an excess of electrons (donors) result in *n*-type conductivity—current carried by free electrons. Impurities deficient in electrons (acceptors) capture other electrons and leave free positive holes that cause *p*-type conductivity. The junction between two parts of a single crystal, one of which is *n*-type and the other *p*-type, behaves as a rectifier. That is, if the current is plotted against the voltage across the junction, then for one polarity of the voltage (forward direction) the junction exhibits a low resistance. For the opposite polarity of the voltage (reverse direction), the junction exhibits a high resistance.

Figure 1 shows a typical plot of current versus voltage through a crystal junction. In the reverse direction, the current varies only slightly with the voltage until the latter approaches a critical value; the current then increases rapidly. The voltage at which the current tends to become infinite is called the breakdown voltage, and in general, it is quite sharply defined. Much effort has been devoted to determining the basic processes responsible for this phenomenon of electrical breakdown.

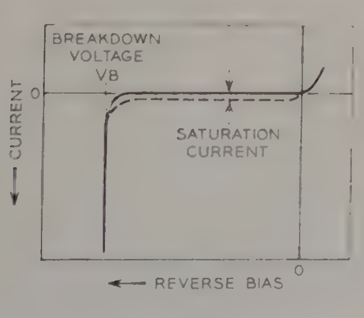


Fig. 1—A typical plot of current versus reverse bias through a semiconductor junction.

This article outlines the experiments, and their results, that have led to our present knowledge about breakdown in *p-n* junctions and its associated phenomena. This discussion is confined to breakdown processes occurring at the *p-n* junction within the body of the crystal, and thus excludes surface effects. Although many of the basic processes are no doubt common to *p-n* junctions in general, this account is concerned with *p-n* junctions in silicon, the material for which the most comprehensive data exist.

To describe the behavior of a *p-n* junction in terms of electronic processes, it is convenient to use the energy diagram shown in *Fig. 2*. In this diagram the potential energy for electrons is plotted as ordinate, against distance through the crystal as abscissa. The diagram can be more easily interpreted if electrons are pictured as trying always to "drop down" (holes try to "climb up" because of different sign) to minimize their potential energy.

The energy diagram consists of three parts. The lowest region of the diagram—the valence band—represents a set of allowed energy levels which normally are almost fully occupied by electrons. The top region of the diagram—the conduction band—represents a set of allowed energy levels which are almost empty. (Energy *bands* in crystals can be regarded to some extent as the solid-state equivalent of energy *levels* in single atoms.) Between the two bands is the "forbidden region" where electrons cannot reside except at localized energy levels associated with the impurities (for example, with the donors and acceptors).

As a result of thermal agitation, electrons (from the donors) are always present in the conduction band of the *n*-type material. These free electrons cause *n*-type

† From an article in the February 1958 issue of Bell Laboratories Record by special permission of Bell Telephone Laboratories, Inc.

**Research in Physical Sciences, Bell Telephone Labs., Inc.*

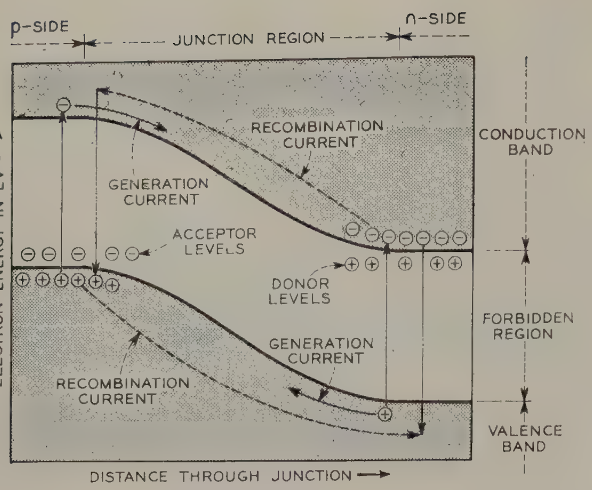


Fig. 2 — The energy diagram of a p-n junction: potential energy of an electron versus its distance through the crystal showing the "forbidden region."

conductivity. Also, in the p-type material electrons from the valence band are captured by the acceptors, and leave free positive holes that cause p-type conductivity. Imagine the two regions as two separate crystals (n-type and p-type) electrostatically neutral and in perfect contact. The free electrons from the n-side tend to spill over into the p-side, thus making the p-side negative with respect to the n-side. A similar process works for the holes—holes spilling over from the p-side to the n-side also will aid in making the p-side negative with respect to the n-side. In the energy diagram, this charging effect is indicated by the p-side being raised relative to the n-side.

The electrons that reach the p-side combine there with the holes. At the same time, thermal agitation excites a small but steady supply of electrons, raising them from the valence band to the conduction band. On the p-side, these thermally-generated electrons (on the p-side free electrons are termed minority carriers) can diffuse to the junction and be swept to the n-side. In equilibrium, the rate at which electrons leave the n-side for the p-side and recombine is equal to the rate at which the electrons thermally generated on the p-side diffuse to the junction, and so reach the n-side. A similar situation also applies to the positive holes in the valence band. These equilibrium conditions determine the height of the potential barrier between the n- and the p-sides when no external voltage is applied to the crystal.

When a reverse bias is applied to the junction, the p-side of the energy diagram is raised still further relative to the n-side. Thus, electrons can no longer go from the n-side to the p-side, nor can holes go from the p-side to the n-side, because of the high potential barrier. The only current flowing across the junction is a constant one due to those carriers thermally generated on either side of the junction (electrons on the p-side and holes on the n-side) that manage to diffuse to the junction. This current, therefore, depends only on the rate of generation of the carriers which, in turn, is independent of the voltage across the crystal. The constant current is called the "saturation" current; it is usually too small to show up on oscillograph traces of the rectifier characteristic. A specific objective of the research described in this article was to determine why, at higher biases, the reverse current departed from the saturation value and eventually led to the unexplained breakdown.

More than twenty years ago, the American physicist Clarence Zener made theoretical investigations of the problem of electrical breakdown in insulators. He concluded that at high but experimentally realizable fields, electrons could be torn from the valence band and raised to the conduction band at a rate sufficient to account for large breakdown currents; this process is called "internal field emission." When breakdown was first observed in p-n junctions, scientists thought it was caused by internal field emission, because very high field-strengths could be produced in narrow junctions. In fact, the breakdown voltage of junctions was often called the Zener voltage. This misnomer has persisted even though subsequent work has shown that, in general, another process is responsible for breakdown.

When an extra number of minority carriers are freed close to the junction (for example, by means of an externally-applied flash of light) some will diffuse into the high-field region and produce a pulse of current. The magnitude of this current is determined by the number of carriers crossing the junction per second. The amplitude of the current pulse, measured as a function of the low reverse bias applied, is found to be constant. At a certain "threshold" bias, however, the current starts to increase. This current grows rapidly as the bias continues to increase until, close to the breakdown voltage, it is very many times its original value.

Evidently at higher biases, more carriers cross the junction than are injected by the light. This condition is called "charge multiplication," and it provides the clue to the cause of breakdown. Consider an electron entering the junction at the p-side, as indicated in *Fig. 3 (a)*. Its passage through the junction (the region that encompasses the high field and is finite in width) is decided by a competition between two processes: (1) the high field tries to accelerate the electron, but (2) during its journey, the electron interacts with other electrons bound to the crystal lattice and tends to lose the kinetic energy it gains from the field. In *Figure 3 (a)*, the horizontal portions of the zig-zag line depicting the electron path represent the first process. The vertical portions represent the energy losses resulting from the second process.

If the field is sufficiently high, the electron will gain energy faster than it loses it. It may even reach an energy state (found experimentally to be 2.3 electron volts for silicon) where, in a subsequent collision, it

can knock a valence electron up to the conduction band. This energy is called the "threshold for pair-production" since the original electron has created two new carriers—the new electron in the conduction band and the positive hole it leaves behind in the valence band.

Each of the the two free electrons can now repeat the pair-production process if there is, in the high-field region, sufficient travel left to them. The hole (which will move in the opposite direction) likewise can gain energy from the field and furnish pair-production. This mechanism may be pictured as providing positive feedback; the two carriers produced by the energetic hole can, in their turn, go on to produce more free carriers, and so on. In a high enough field, the processes initiated by the entry of one free carrier into the junction will build up to an "avalanche" with correspondingly high currents, see *Fig. 3 (b)*. Investigation of the multiplication behavior has shown that breakdown occurs by this avalanche mechanism in all but the narrowest of germanium and silicon *p-n* junctions.

Several decades ago the English physicist J. S. Townsend proposed that an avalanche mechanism was the reason for electrical breakdown in gases. Some of the equations he developed are identical in form to the ones now used to express the amount of charge multiplication as a function of the reverse bias applied to the semiconductor junction. As a further analogy, the most significant result obtained from measurements of the charge multiplication is the dependence of the ionization rate on the electric field. Ionization rate can be defined as the number of electron-hole pairs produced per centimeter of path by a carrier traveling in a uniform field. Recent accurate measurements of the amount of charge multiplication as a function of the bias show that the ionization rate in semiconductors varies with the field in a way very similar to its behavior in gases.

Visible radiation is emitted during breakdown—another feature in common with gases. This is best observed in a silicon *p-n* junction designed like that of the Bell Solar Battery;* that is, the junction must lie parallel and very close to the polished surface of the crystal. Light originating at the junction thus is not absorbed too greatly within the crystal; rather it emerges through the top layer. Contrary to what one might expect, the light emission does not appear as a uniform glow extending over the whole area of the junction. Instead, it appears as many very small, intense spots distributed in a random fashion. Tests have shown that all the breakdown current streams through these spots—each spot carries about 100 microamperes. These light-emission patterns provide direct evidence that breakdown is a body property and is not confined to the surface.

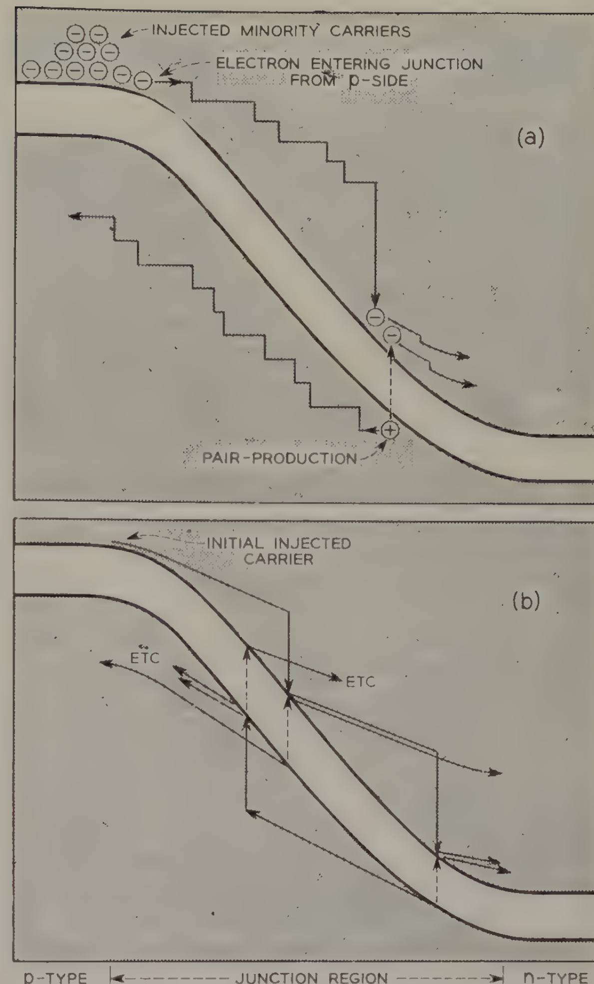


Fig. 3 — Charge multiplication at (a) moderate reverse bias, and (b) high reverse bias. The zig-zag lines of (a) are drawn as straight lines in (b) to simplify the representation of this latter process.

Recourse can be made to the methods of gas discharge analysis to explain why spots of light, rather than a uniform glow, appear on the crystal surface. Analysis of the *p-n* junction has shown that it is quite feasible for a highly localized (a few hundred angstroms in each direction), quasi-stable avalanche condition to be created, and that this condition is self-limiting in regard to current. The local region of breakdown has been named a "microplasma" by analogy with the terminology of gas-discharge physics.

Another feature of *p-n* junction rectifiers has been related to these light spots. At a bias just below breakdown, the junction is observed to become very noisy. This noise consists of short, square pulses of current, of about 100 microamperes each. A pulse, which switches on and off very suddenly, may last from less than a few tenths of a microsecond to several microseconds. If the breakdown current is increased slowly and continuously from a low value, definite sets of noise pulses appear at certain biases. In some junc-

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tions it has been possible to distinguish up to twenty sets of noise pulses. A typical display of these pulses is shown in *Fig. 4*.

A set of noise pulses can be correlated with the appearance of a new light-emitting spot. The intermittent nature of the avalanche breakdown of one of these spots can perhaps be explained by the possibility that occasionally a sufficient number of carriers fail to produce multiplication when they cross the junction. This would terminate the avalanche until another statistical fluctuation of pair-production in the other direction turns it on again.

Spectrum measurements suggest two possible mechanisms for the origin of the light emission: (1) recombination radiation—where an electron in the conduction band falls into a positive hole in the valence band; (2) de-excitation radiation—where an energetic carrier suddenly loses some of its energy but remains in the same energy band. The former mechanism must account for the most energetic photons emitted; photons up to 3.2 electron volts of energy (blue wavelengths) have been observed. Since the energy gap between the conduction and valence bands corresponds to 1.1 electron volts in silicon, the existence of 3.2-electron volts photons requires recombination between electrons and holes where at least one of these possesses high kinetic energy. Very few electrons can exist in an energy state greater than about 2.3 electron volts, the energy found to be necessary for pair production. It is much more probable that the electron will lose such energy by the pair-production process rather than by processes of the emission of light.

At the other end of the energy scale (infra-red wavelengths), photons with energies considerably less than the band gap (1.1 electron volts) have been detected. Obviously, these cannot be produced by recombination. They are suspected to result when energetic carriers suffer a sudden loss of energy but remain within the same energy band. Such a process could account for photons with energies ranging from very small values up to about 2.3 electron volts. *Fig. 5* depicts the two types of processes responsible for the light emission. It is interesting to note that avalanche breakdown constitutes one of the best understood ways of producing electro-luminescence.

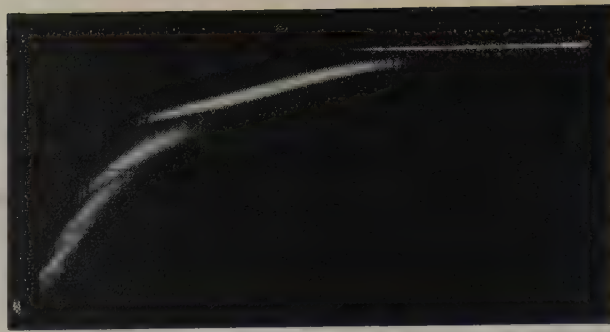


Fig. 5 — Theory of production of light by recombination "R" and de-excitation "D" transitions.

The behavior of very narrow junctions (those a few hundred angstroms in width) has been found to differ in several respects from that of the wider junctions exhibiting avalanche breakdown. In wide junctions the breakdown voltage increases with temperatures; in narrow junctions it decreases. Also, narrow junctions exhibit extremely high reverse currents which are relatively insensitive to temperature. In fact, experiments have shown that the high reverse currents in narrow junctions are produced by the internal field emission, originally thought to be responsible for breakdown in all *p-n* junctions.

The study of basic breakdown processes in *p-n* junctions is leading us to a more detailed understanding of the behavior of electrons and holes in crystals. Furthermore, out of such studies comes much of the information required for the design of many semiconductor junction devices.

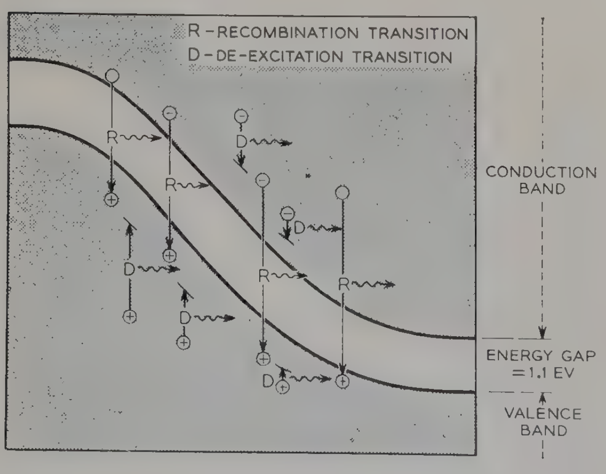


Fig. 4 — Each step in the curve represents the onset of the unstable breakdown condition that is associated with a particular light spot.

SELECTED LIST OF BTL TECHNICAL PAPERS CONCERNED WITH THE BASIC PROCESSES IN P-N JUNCTION BREAKDOWN:

K. G. McKay and K. B. McAfee, Phys. Rev. *91*, 1079 (1953) Electron Multiplication in Silicon and Germanium.
K. G. McKay, Phys. Rev. *94*, 877 (1954) Avalanche Breakdown in Silicon.
P. A. Wolff, Phys. Rev. 95, 1415 (1954) Theory of Electron Multiplication in Silicon and Germanium.
S. L. Miller, Phys. Rev. *99*, 1234 (1955) Avalanche Breakdown in Germanium.
S. L. Miller, Phys. Rev. *105*, 1246 (1957) Ionization Rates for Holes and Electrons in Silicon.
A. G. Chynoweth, Phys. Rev. Vol. 109 Ionization Rates for Electrons and Holes in Silicon.
A. G. Chynoweth and K. G. McKay, Phys. Rev. *102*, 369 (1956) Photon Emission from Avalanche Breakdown in Silicon.
A. G. Chynoweth and K. G. McKay, Phys. Rev. *106*, 418 (1957) Internal Field Emission in Silicon p-n Junctions.
A. G. Chynoweth and K. G. McKay, Phys. Rev. *108*, 29 (1957) Threshold Energy for Electron-Hole Pair-Production by Electrons in Silicon.

Marketing and Production Trends in the Semiconductor Industry

H. E. MARROWS†

The race among manufacturers of semiconductor devices is toward higher operating frequencies, greater power handling capabilities, and higher operating temperatures. This article discusses transistor manufacturers, their processes, their suppliers and their products.

LOOKING back some seven years or so, the early transistors now seem pretty crude devices. The flush of new discovery masked device limitations in optimistic eulogies of developments. Some of the early predictions are rapidly coming true, but only after intense studies, painstaking experiments and brilliant flashes of intuition on the part of research men. There have been some painful casualties too, with several manufacturers falling by the wayside. Right now, some twenty-odd manufacturers in the United States are striving to make transistors that are needed for the numerous applications which have arisen.

From the beginning the race has been toward higher operating frequencies, greater power handling capabilities and higher operating temperatures. Along with these basic objectives have come other requirements of particular applications. Higher operating voltages to meet various power supplies, to handle transient voltage surges or to meet certain circuit designs. Small as they are, transistors have to be made smaller for the new hearing aids. Notoriously noisy in the early days, the devices had to have lower noise figures for the low level applications they first attracted. And so it goes, as application upon application piles up.

TABLE I

A LIST OF SUPPLIERS OF BASIC SEMICONDUCTOR MATERIALS

GERMANIUM
Accurate Specialties Co., Inc.*
American Steel & Wire Div.
American Zinc Company
Eagle Pitcher Co.
Foundieries de Zinc de la Vieille Montagne (Belgium)
Johnson, Mathey Co. (England)
National Zinc Co.
Saratoga Laboratories
Sylvania Electric Products, Inc.**
Tsumeb Corp. (Africa)
Union Miniere du Haut Katanga (Africa)

SILICON
E. I. du Pont de Nemours & Co. (Inc.)
Merck & Co.
Semimetals, Inc.***
Knapic-Electro-Physics Inc.***

OTHER MATERIALS, ALLOYS & CHEMICALS#
Accurate Specialties Co., Inc.
Alpha Metals, Inc.
Baker & Adamson Products
The Consolidated Mining & Smelting Co. of Canada Limited
The Indium Corporation of America

* *Germanium preforms*

** *Also single crystals*

*** *Single crystals*

\# *Among these are the following: metals-indium, antimony arsenic, bismuth, tin, aluminum, gold, silver, nickel, kovar, platinum, lead, and alloys. Some of these may be obtained in preforms. Various cleaning and etching chemicals are available from Baker & Adamson Products.*

† *Author "Transistor Engineering Reference Handbook"*

Materials and Cleanliness

Manufacturers have gone a long way from the pulsed point contact. To recount some of the advances, we can begin with the basic materials and their qualities, for it is here that the manufacturer must make some basic decisions on the direction of his efforts. About ten suppliers of germanium meet the demands of the industry. Silicon is supplied largely by E. I. du Pont, but others are entering the field. Merck & Co., Inc., has just started production in Danville, Pa. Table I shows a list of some suppliers of basic materials.

At the present time all transistors are being made of either germanium or silicon, although one company (Clevite) has come forward with diodes of a germanium-silicon alloy. While a large company can follow both silicon and germanium roads, a smaller company must almost tie its future to one or the other. In terms of marketing what does this mean? In general, the answer to this may be put this way: for low cost units, for high frequency and general purpose applications, the germanium road is correct for the immediate future. For high temperature applications, the military market, many industrial applications, special applications and the long range future, the road points to silicon. The long range future, of course, will also involve intermetallic compounds.

In working with germanium and silicon over the years, manufacturers have found that cleanliness in all phases of processing are a must to prevent contamination. Assuming single crystals are sliced, diced, and lapped or polished, then etched, a number of water-soluble materials as well as lint and dust remains on the wafers. Ultra-sonic cleaning techniques are successful in removing physical contaminants such as lint or dust not chemically bonded to material. Etching debris of inorganic materials which are ionic are effectively removed by washing with distilled water, continuously circulated. Further cleanliness is maintained throughout the fabrication cycle, using dust-free, air-conditioned rooms and "dry boxes." The latter are used mainly for the final stages, where an operator, with gloved hands, handles the transistor assemblies. Long time studies have shown that cleanliness pays off with significant improvements in voltage-current characteristics, break-down voltages, saturation currents, emitter reverse impedance as well as in other characteristics.

Processing

Plans for highly mechanized production of transistors have been in formulation stages for some time, but unfortunately new developments have come along to delay or to make them ineffective. Suppliers of manufacturing equipment are looking in this direction and Table II, shows a list of standard equipments and tools developed for the trade.

There have been many improvements made in refining, growing of single crystals, and preparation of wafers for semiconductor products. However, significant developments in the actual fabrication of transistors have taken the limelight.

The outstanding development is the use of gaseous diffusion for making base layers. Until this technique came along, the bulk of transistors offered were the alloyed, grown junction types and electroplated surface barrier transistors. Diffused layer types are now starting to make a serious bid to compete or be combined with the older processes, despite initial high costs and despite the newness of the process. *Fig. 1* shows the relative status of the types being offered.

In 1956 three companies announced the availability of the diffused layer types: Radio Corporation of America, Texas Instruments, Inc. and the Western Electric Company, Inc., the last company's being available only to the U. S. Military agencies and their contractors.

In diffused layer transistors the diffusion process is used to incorporate a non-uniform (graded) distribution of impurities in order to create an internal electric field which speeds up charge carriers from emitter to collector. Decrease in transit time brings the frequency response in the hundreds of mega-

TABLE II

SUPPLIERS OF EQUIPMENT AND TOOLS FOR THE MANUFACTURERS OF SEMICONDUCTORS

CRYSTAL GROWING EQUIPMENT

Semimetals, Inc.
Marvelco Electronics Div.
Kahle Engineering Company

GLASS BEADING MACHINE

Eisler Engineering Co., Inc.

VACUUM PUMPING

V. M. Welch Scientific Company

DRY BOXES

P. M. Lennard Co., Inc.

WAFERING MACHINES (For Slicing and Dicing)

Micromech Mfg. Corp.
Felker Manufacturing Co.

FURNACES

BTU Engineering Co.
Hevi-Duty Electric Co.

ULTRASONIC CUTTING TOOLS

Cavitron Equipment Corp.

MICROMANIPULATORS

Brinkman Instruments, Inc.

MICROSCOPES

Bausch and Lomb Optical Co.

WELDING EQUIPMENT

Weldamatic Div. of Unitek Corp.

MARKING MACHINES

Popper & Sons, Inc.

SEALS AND CLOSURES

Electrical Industries, The Hermaseal Co., Inc.,
Hermetic Seal Products Co.

cycles. It is said that the optimum impurity distribution is exponential with distance in the base.

The Bell Telephone Laboratories have been using the diffusion process for some time in the making of experimental silicon photocells for conversion of solar radiation to electrical power, power rectifiers and lightning protectors as well as experimental transsistors. The Western Electric Laureldale, Pa. plant, a U. S. Army Signal Corps sponsored facility, in 1956, started making diffused base germanium transistors with a median alpha cut-off of 500 *mc*—with the figure now being several hundred *mc* higher.

Texas Instruments is now offering all-diffused silicon types, the latter being used for power applications. Philco Corporation has announced micro-alloy diffused-base transistors (MADT) for the VHF frequencies, with some usable as oscillators over 1,000 *mc.*

Although significant advances have been made in the alloyed and grown types—particularly rate-growing and meltback—the diffusion types, by their remarkable increases in frequency capabilities, have captured the eye of the circuit designers. They also show great promise for power applications, an example of which is the 85-watt dissipation silicon type (2N451) of General Electric Company (25 watts, Class A, sine wave). It must be remembered, however, that the present diffused layer types still use alloying techniques for the emitter and growing for the collector in most cases.

The gaseous diffusion process has brought on many new problems to the manufacturer. Higher processing temperatures are involved, purer and cleaner materials are required and new techniques of masking and etching have to be devised. Even the simple act of connecting electrical leads to semiconductors takes a great deal of study and experimentation. Ingenious methods, like the ones shown in *Fig. 2* are being brought forth almost daily in the literature.

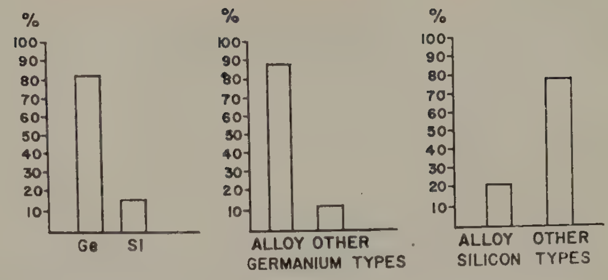
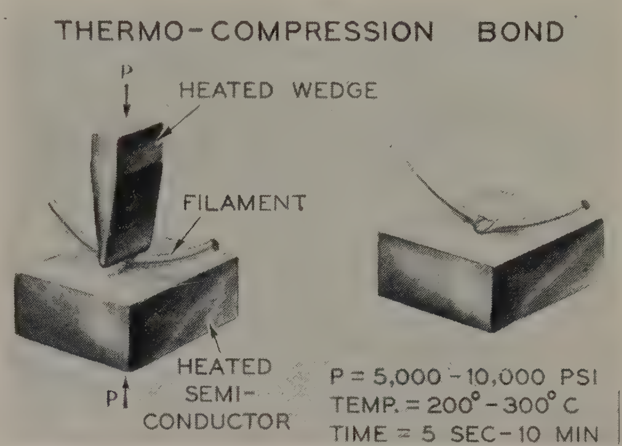
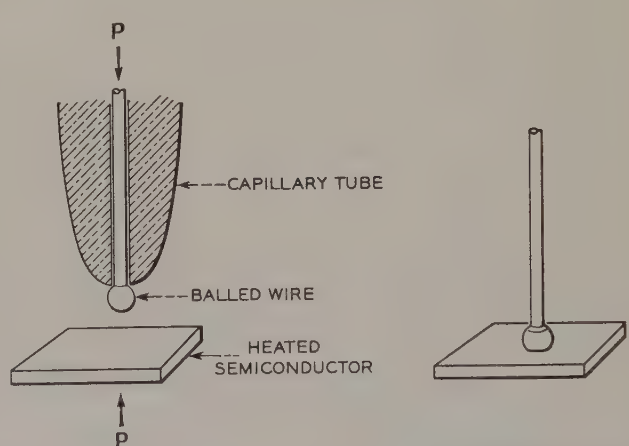


Fig. 1—Distribution of commercial transistor types.



(*Courtesy Bell Tel. Labs.*)

Fig. 2A—Thermo-compression bond.



(*Courtesy Bell Tel. Labs.*)

Fig. 2B—Thermo-compression bonding mechanism.

Testing and Aging for Reliability

One of the advances the transistor industry has to make is the matter of presenting design data to the circuit designer in a better way. Although aging is a normal process that all manufacturers have adhered to, the results of aging are now better understood and aging tests are made under a variety of simulated usages rather than to some particular circuit requirements or systems. Most transistor designs today show rapid changes the first few hours of aging, but these changes become very gradual with time. There is no doubt that testing and aging, properly planned, will afford sufficient data so that the product can be wisely used and its reliability determined. In the early years of commercial work with transistors, this data was seldom available. More and more, however, manufacturers are giving the designer a better idea of what he may expect in terms of variations in parameters.

Characteristics and Structures

Figures 1, 3, and *4* show interesting statistics of over 400 transistors being offered in the United States at the end of 1957. The statistics used do not include the special switching types of units such as the General Electric unijunction, the Shockley diode, or Westinghouse dynistor types, nor the photodiodes. These units, which perform so many functions not strictly in the diode family, number about two dozen

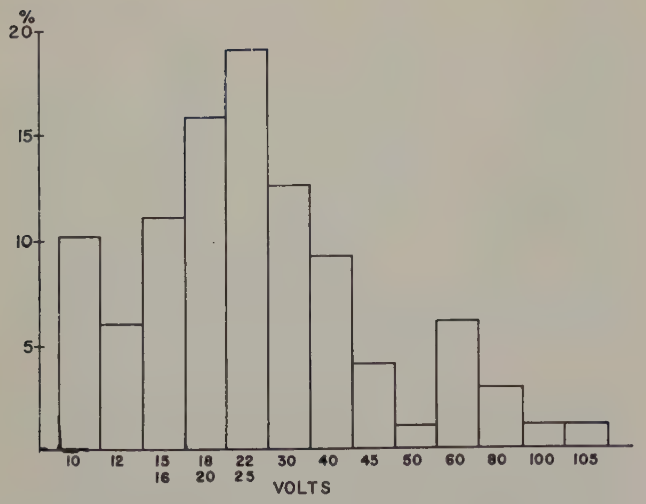


Fig. 3A—Distribution of germanium transistors by maximum collector voltage.

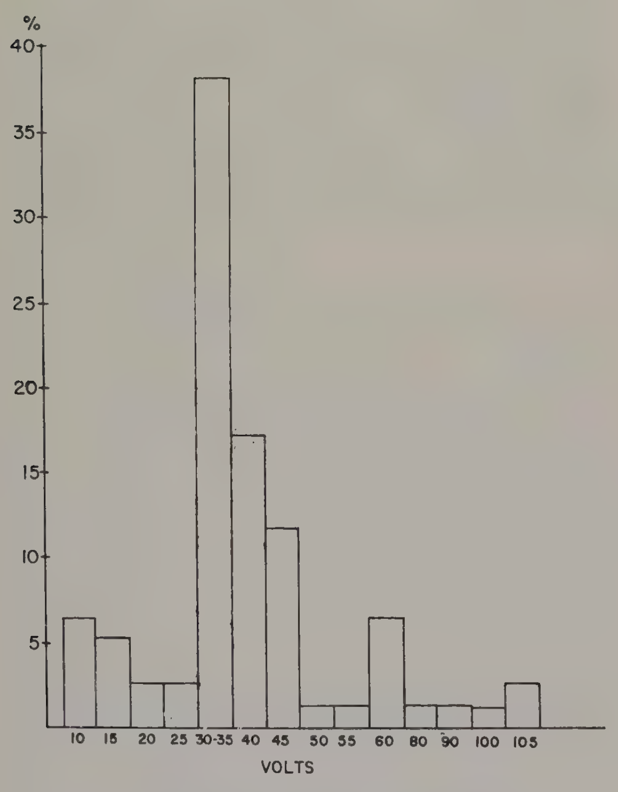


Fig. 3B—Distribution of silicon transistors by maximum collector voltage.

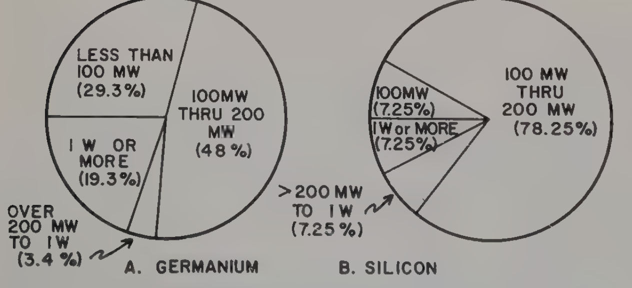


Fig. 4—Distribution of commercial transistors by maximum collector dissipation.

codes. Point contact transistors, less than a dozen of which are made in the United States, have also been omitted from the statistics.

In *Fig. 1* it is evident that although the alloy types are predominant with germanium transistors, the silicon types are beginning to utilize the growing and gaseous diffusion processes to a greater extent. This is probably due to economic reasons. The silicon transistors are generally required for special applications where higher prices are not deterrents.

Figures 3 and *4* indicate the growing trends to transistors with higher operating voltages and more power as newer applications enter the picture. From *Figs. 3A* and *3B* we observe that the bulk of the higher voltage transistors are pointed toward 12 and 28 volt power supplies used in automobile, telephone and computer circuits. Some 80 volt types such as the Bendix X113 and X133 are particularly suited to inverter circuits. RCA's 2N398, a 105 volt type, is employed as an "on-off" control for indicating circuits. Tung-Sol's 2N459 and Delco's DT100 105 volt transistors are used for high power switching. Bogue Electric has two silicon transistors, X-32 and 2N349 which have maximums of 125 volts for power applications in the radio frequency ranges. *Fig. 4* shows the distribution of commercial transistors by maximum collector dissipation.

A significant note appears in the maximum allowable temperatures in transistor specifications. Better designs such as the Tung-Sol 2N460, indicate storage and junction operating temperatures of 100°C for germanium transistors. Another example in silicon transistors shows Texas Instruments' 2N497 and 2N498 giving temperature maximums of —65°C to +200°C. Ambient temperature specifications are not as useful as junction temperature specifications because special structures and special heat dissipating arrangements can change design possibilities drastically. This latter point has made it especially difficult to compare power transistors from some manufacturers' specifications.

Structures will continue to change and there is a moderate trend toward the new JETEC cases. A number of companies have structures and cases which are appealing to certain applications. Amperex has some all-glass encasements for good hermetical sealing. Hughes Aircraft's line of transistors with a coaxial type case seems to be especially suited for mechanized manufacturing. Philco has subminiature transistors which are appealing to hearing aid and military equipment designers. A number of companies have some ingenious power structures. Looking toward the future, U. S. Army scientists recently disclosed work on methods of "printing" transistors by photolithographic processes.

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Dot Material for Alloy Junction Type Semiconductors

FREDRICK C. DISQUE, JR.*

Information on the availability of dot material of various compositions, purities, and forms is discussed for the benefit of the engineer concerned with semiconductor device manufacture.

THE TERM "dot material" is commonly used by the semiconductor industry to describe pellets, discs, washers, spheres, and other forms of p-type alloys and n-type alloys used in the alloy process to form junctions in solid state devices.

In forming an alloy junction with germanium or silicon, a dot containing one or more of the elements of Group III-A (p-n junction) or a dot containing one or more of the elements of Group V-A (n-p junction) is used.

Group III-A	Melting Point (°C)	Group V-A	Melting Point (°C)
Boron	2300	Nitrogen	—210
Aluminum	660	Phosphorus	590
Gallium	30	Arsenic	814
Indium	155	Antimony	630
Thallium	305	Bismuth	271

The choice of the element to be used is determined by a number of considerations including its distribution coefficient in germanium or silicon, its diffusion constant, and physical characteristics. From the standpoint of emitter efficiency, it is desirable to use the element with largest distribution coefficient ($K = C_{solid}/C_{liquid}$). While precise values of the distribution coefficient are not known because of the difficulties in measurement at the low solute concentrations where the laws of solution are valid, approximate values indicate that the coefficient decreases with increasing atomic number. Thus, it would be most desirable to use the elements occurring at the top of the respective groups in the periodic table.

P-Type Dot Material

Ideally, boron should be used in forming a p-n junction since it has the greatest solubility of the Group III-A elements and should produce a junction with the largest emitter efficiency. Unfortunately, the high melting point of boron makes it unsuitable as alloying material. Alloys containing boron have been suggested and tried but the difficulty of obtaining boron of sufficient purity and its limited solubility in most metals has discouraged its use.

Aluminum is the next best choice for alloying material. For silicon devices it works quite well but the problems of attachment of leads to the aluminum dots, the relatively high firing temperatures required, and cracking of the units because of different coefficients of expansion of aluminum and silicon have made this element considerably less than ideal as an alloying material. Alloy combinations of aluminum and gallium have been used with success. Aluminum-tin alloys have been tried but these alloy combinations are unstable because of galvanic action which takes place between the aluminum and tin in the presence of moisture. The limited solubility of aluminum in indium rules out aluminum-indium alloys. However, considerable interest is being shown in a laminated or sandwich type dot material consisting of alternate layers of aluminum and indium. If the problems of producing this material economically can be solved, it may lead to an improvement of emitter efficiency. Aluminum is not used as an alloying material with germanium to any great extent at the present.

Gallium, because of its low melting point, cannot be formed into a pellet or sphere which is practical to store or handle. Combinations of gallium and indium are the most popular for emitter dots. Gallium-indium alloys with more than 0.5% gallium are difficult to make in forms other than spheres because of the brittleness of the alloy. New metallurgical techniques are being developed to produce higher gallium content alloys.

Indium, although having a relatively poor distribution coefficient has the proper melting point, ductility, and purity to make it quite suitable for use as collector dot material.

Thallium, as the element or in alloys is rarely used.

N-Type Dot Material

Nitrogen is completely unsuitable because it is a gas at room temperature.

Phosphorus, because of its volatility, non-metallic character, and chemical activity cannot be used as an alloying material. Difficulties in producing homogen-

** Director of Research, Alpha Metals, Inc.*

ous alloys containing phosphorus have been encountered.

Arsenic, because of its high melting point, high vapor pressure and lack of ductility is not suitable for forming into useable shapes. Combinations of lead and arsenic are popular and certain other alloys of arsenic have been used.

Antimony is too brittle to be formed into discs. It can, however, be provided in spherical shape. Alloys of lead and antimony are the most popular n-type alloying material.

Purity of Alloy Dot Material

The germanium and silicon used in semiconductors are refined to an extremely high degree by zone refining techniques. The quantity of impurities present after refining is so minute that none of the conventional methods of chemical analysis are sensitive enough to identify or determine the amount present. The purity is determined by measuring the electrical resistivity of the material. This method cannot be used for measuring the purity of metals and alloys commonly used for forming alloy junctions. Metals have low resistances and these are not measurably changed even with large quantities of impurities present. Spectrographic techniques are most commonly used for analyzing the alloys. Impurity levels of one to ten parts per million can be determined with the spectrograph depending upon the elements determined. The exact role that trace quantities of lead, tin, copper, zinc, etc., play when present in the alloy dot material is not known. However, there can be little doubt that it is desirable to use the highest purity available in any given doping alloy. Indium is available in commercial quantities at the 99.999 per cent purity level with 99.9999 per cent obtainable by selecting certain carefully prepared lots. Aluminum and gallium are available commercially in a 99.99 per cent grade with 99.999 obtainable when desired. Tin and lead of 99.99 per cent purity are available in commercial quantities. The best grade of arsenic and antimony in commercial quantities is 99.99 per cent.

Basic Melts

In order to obtain uniformity in dot material some semiconductor fabricators are taking advantage of the basic melt principle. This principle is based on the assumption that uniformity in alloy composition and impurity level in alloy dots is a significant factor in increasing the yield in semiconductor devices. The system works as follows: a batch of alloy is carefully prepared in one melting vessel and cast in a form suitable for rolling or extrusion. The batch is analyzed for minor constituent content and spectrographically for impurities. If the analysis shows the alloy to be within specification, it is then further processed. This processing involves extrusion or rolling the entire batch of material at one time on one extrusion press or rolling mill. This is done in order to insure against contamination pick-up from the extrusion or rolling operation. If part of the material is processed at one time and the balance at some other time, it is readily apparent that contamination will vary, leading to non-uniformity in the finished dots. Finally, the dots are all punched at one time on the same press with the same tools. A representative sample of the finished dots is then analyzed.

Forms of Dot Material

Alloy dot material is available in the form of discs, spheres, washers, and other shapes. The actual form selected depends upon a number of factors, the most important of which are:

Device design
Dot Alloy material
Dot size

The device designer generally has some latitude in his requirements and should be familiar with the forms available for a given alloy and the limitations placed on the design by the physical characteristics of the material specified. Certain guiding principles should be remembered:

1. The diameter of the disc should be greater than its thickness.
2. The wall width of a washer should be greater than its thickness.
3. Avoid specifying discs with diameters less than .008″ (Specify a sphere of equivalent volume if possible).
4. Avoid specifying spheres with diameters greater than .060″ (Shrink holes occur making weight consistency difficult. Specify a disc of equivalent volume if possible).
5. Avoid disc thicknesses under .003″ (For soft materials, thickness will vary considerably introducing relatively large volume variations).

Certain alloy combinations are too brittle to roll or extrude and therefore are not suitable for fabrication into discs or washers. Very often, however, these alloys can be provided in spherical form.

For high frequency devices fusion dots of small volume are required. Generally a sphere is the recommended form for this application since spheres can be produced having much smaller volumes than discs. Spheres with diameters as small as .002″ have been successfully produced. Spheres are becoming more popular because they are more readily handled in automatic feeding devices than discs. It is also believed that better control of the wetted area is achieved with spheres because of the smaller contact surfaces.

Dimensions

In the production of transistors the dimensions of the dot material are of great importance. The depth of alloying and therefore the thickness of the base region is a function of the time-temperature firing

Cleaning dot surfaces by soxhlet equipment.

cycle, the thickness of the semiconductor dice, the rate of cooling, the wettability of the germanium or silicon surface, and other factors. For reproducible results the weight (or volume) of the dot material must be constant. Improvement of fabrication techniques and more rigid inspection procedures have constantly improved this phase of dot material quality. For most alloys it is possible to control the diameter of discs to plus or minus .0005″ of the nominal. Constant inspection and reworking of punches and dies is necessary to maintain these tolerances. The thickness of discs can generally be controlled to plus or minus .0005″ also and in some cases as close as .0001″. Since the volume is a function of the diameter squared and the thickness to the first power, the diameter is the more critical dimension. In those cases where a sandwich type assembly is used, the thickness becomes extremely important in maintaining contact during firing.

Sphere diameters can be controlled to plus or minus .0003″ and in special cases to plus or minus .0001″. While these tolerances are better than those which can generally be achieved with discs, it should not be assumed that spheres afford a better means of weight control. There are many methods of classifying spheres and most of the suitable production methods depend upon devices which sort by means of measuring a dimension rather than by weight classification. For exactly spherical particles the dimensional methods of classification are valid. However, if any reasonable quantity of the spheres are eccentric, the dimensional methods of classification fail.

Surfaces

The importance of clean surfaces cannot be overemphasized. The initial wetting which takes place in the alloying process is extremely important to the quality of the device. The surfaces of dot material should be free of oil, lubricants, and other substances which hinder wetting. Usually etching is done just prior to assembly but since most etchants are aqueous solutions, they will not penetrate organic films. Even vapor degreasing or ultrasonic cleaning fails to remove certain classes of films remaining from the processing of the dot material. Careful manufacturing procedures can eliminate this problem with dot material.

Base Tab Joining

One of the problems of transistor manufacture is that of making a good, reliable attachment of the germanium wafer to a tab. A tab material having the same coefficient of expansion as the wafer is ideal for producing a reliable bond and eliminating cracking. Nickel, rodar, kovar, and certain proprietary iron-nickel alloys are commonly used for tabs. The tabs should be coated with a metal or alloy which will wet the base of the transistor and form a bond between the wafer and tab. An additional requirement is that a non-rectifying ohmic contact be formed. For *p-n-p* type transistors the tab coating should be *n*-type. For *n-p-n* types the coating should be *p*-type material. Certain combinations of tab materials and coatings are now commercially available. Coatings of indium, tin, tin-lead-indium, tin-antimony, and tin-lead-antimony have been produced. For the most part, the industry is looking for better control of the coating to tab ratio and certain combinations of coatings and tabs not yet available. The intensive work being done on this type of product should result in more suitable material being available in the future.

CHARACTERISTICS CHARTS of NEW DIODES and RECTIFIERS

SEMICONDUCTOR PRODUCTS follows up its tabulation of semiconductor devices with a list of newly-announced semiconductor diodes and rectifiers in a format useful to the engineer. This type of information will be released every 4 months. The current listing covers the period of September 15, 1957 through January 15, 1958. We have divided this material into 4 specific characteristics charts—Diodes and Rectifiers, Silicon Zener or Avalanche Diodes, Switching Diodes and Miscellaneous Diode Types—in order to provide the optimum presentation of the parameters describing these devices. In addition, a listing is provided for manufacturers who have announced that they have just begun supplying previously registered diodes and rectifiers. The characteristics of JETEC registered types are those supplied by the manufacturer of each registered type. *These charts are intended primarily as a guide; complete specifications, prices, and availability should be obtained directly from the manufacturers.*

MANUFACTURERS

(In Order of Code Letters)

- AUD— Audio Devices, Inc.
- AUT— Automatic Mfg. Co.
- AMP— Amperex Electronic Corp.
- BEN— Bendix Aviation Corp.
- BER— Berkshire Labs
- BOG— Bogue Electric Mfg. Co.
- BOM— Bomac Labs
- BRA— Bradley Labs
- BTHB— British Thomson-Houston Export Co., Ltd.
- CBS— CBS-Hytron
- CLE— Clevite Transistor Products, Inc.
- CSF— Compagnie Generale de T.S.F. (American Radio Co., Inc.)
- EEVB— English Electric Valve Co., Ltd.
- FAN— Fansteel Metallurgical Corp.
- GAH— Gahagan, Inc.
- GECB— General Electric Co., Ltd.
- GE— General Electric Company, Electronics Division, Semiconductor Products
- HSD— Hoffman Semiconductor Division
- HUG— Hughes Products Division
- IFHS— Institutet for Halvledarforskning
- INRC— International Rectifier Corp.
- IRC— International Resistance Co.
- KEM— Kemtron Electron Products, Inc.
- LCTF— Laboratoire Central de Telecommunications
- MIC— Microwave Associates, Inc.
- MOT— Motorola, Inc.
- MUL— Mullard, Ltd.
- NPC— Nucleonic Products Co., Inc.
- PHI— Philco Corp., Lansdale Tube Company
- PSI— Pacific Semiconductors, Inc.
- RAY— Raytheon Manufacturing Company
- RCA— Radio Corporation of America, Semiconductor Division
- RRC— Radio Receptor Co., Inc.
- SAR— Sarkes Tarzian, Inc., Rectifier Division
- SSL— Shockley Semiconductor Lab, Backman Instruments, Inc.
- SIE— Siemens & Halske Aktiengesellschaft
- SPE— Sperry Semiconductor Division
- STCB— Standard Telephone & Cables, Ltd. (Intelex Systems, Inc.)
- SYL— Sylvania Electric Products, Inc.
- TFKG— Telefunken, Ltd.
- THE— Thermosen, Inc.
- TII— Texas Instruments, Inc.
- TOK— Tokyo Tsushin Kogyo, Ltd.
- TRA— Transitron Electronic Corp.
- USD— United States Dynamics Corp.
- USS— U. S. Semiconductor Products, Inc.
- WEC— Western Electric Co.
- WEST— Westinghouse Electric Corp.

CHARACTERISTICS CHART of DIODES and RECTIFIERS

TYPE NO.	USE {See Code Below}	MAT	PIV	MAX. CONT. WORK. VOLT.	Min. Forward Current @ 25°C I_f @ E_f	MAX. D.C. OUTPUT CURRENT[4] @ T (°C)	MAX. FULL LOAD VOLT. DROP[4]	Max. Rev. Current I_b @ E_b @ T	MFR. {See code at start of charts}
			(volts)	(volts)	(mA) (volts)	(amps)	(volts)	(uA) (volts) (°C)	
1N52A	1	Ge		50	5.0 @ 1.0			100 @ 50 @ 25	SYL
1N198A	1	Ge	100	80	4.0 @ 1.0			250 @ 50 @ 75	SYL
1N330	1	Si	32		3.0 @ 1.0			.03 @ 20 @ 25	WEC
1N331	1	Si	16		5.0 @ 1.0			.01 @ 10 @ 25	WEC
1N411B	2	Si	50	50		50 @ 150	1.5	15 ma @ 50 @ 150	INRC, TRA
1N412B	2	Si	100	100		50 @ 150	1.5	15 ma @ 100 @ 150	INRC, TRA
1N413B	2	Si	200	200		50 @ 150	1.5	15 ma @ 200 @ 150	INRC, TRA
1N547	2	Si		600		.250 @ 150A	1.2	10 @ 600 @ 25	TRA, AUT
1N636	1	Ge	60	45	2.5 @ 1			10 @ 10 @ 25	CBS
1N645	2	Si	225		400 @ 1	.150 @ 150	1	.20 @ 225 @ 25	RAY
1N646	2	Si	300		400 @ 1	.150 @ 150	1	.20 @ 300 @ 25	RAY
1N647	2	Si	400		400 @ 1	.150 @ 150	1	.20 @ 400 @ 25	RAY
1N648	2	Si	500		400 @ 1	.150 @ 150	1	.20 @ 500 @ 25	RAY
1N658	1	Si	120	100	100 @ 1			25 @ 50 @ 150	RRC
1N673	1	Si	250	200	.250 @ 1.0			2.0 @ 200 @ 25	WEC
1N676	2	Si	100	100	200 @ 1.0	.200 @ 25	1.0	1.00 @ 100 @ 25	TRA
1N677	2	Si	100	100	400 @ 1.0	.400 @ 25	1.0	1.00 @ 100 @ 25	TRA
1N678	2	Si	200	200	200 @ 1.0	.200 @ 25	1.0	1.00 @ 200 @ 25	TRA
1N679	2	Si	200	200	400 @ 1.0	.400 @ 25	1.0	1.00 @ 200 @ 25	TRA
1N681	2	Si	300	300	200 @ 1.0	.200 @ 25	1.0	1.00 @ 300 @ 25	TRA
1N682	2	Si	300	300	400 @ 1.0	.400 @ 25	1.0	1.0 @ 300 @ 25	TRA
1N683	2	Si	400	400	200 @ 1.0	.200 @ 25	1.0	1.0 @ 400 @ 25	TRA
1N684	2	Si	400	400	400 @ 1.0	.400 @ 25	1.0	1.0 @ 400 @ 25	TRA
1N685	2	Si	500	500	200 @ 1.0	.200 @ 25	1.0	1.0 @ 500 @ 25	TRA
1N686	2	Si	500	500	400 @ 1.0	.400 @ 25	1.0	1.0 @ 500 @ 25	TRA
1N687	2	Si	600	600	200 @ 1.0	.200 @ 25	1.0	1.0 @ 600 @ 25	TRA
1N689	2	Si	600	600	400 @ 1.0	.400 @ 25	1.0	1.0 @ 600 @ 25	TRA
1N1096	2	Si	600			.750 @ 25			GE, TII, TRA, AUT
1N1119	2	Si	500	500		1.5 @ 70	0.65	300 @ 500 @ 150	GE
1N1120	2	Si	600	600		1.5 @ 70	0.65	300 @ 500 @ 150	GE
1N1124	2	Si	200	200		1.0 @ 150		10 @ 200 @ 25	TII
1N1125	2	Si	300	300		1.0 @ 150		10 @ 300 @ 25	TII
1N1126	2	Si	400	400		1.0 @ 150		10 @ 400 @ 25	TII
1N1127	2	Si	500	500		1.0 @ 150		10 @ 500 @ 25	TII
1N1150A	2	Si	1600			.750 @ 100	6.0	2000 @ 1600 @ 25	SAR
1N1263	2	Si	50			150 @ 100	1.25	150MA @ 50 @ 25	SAR
1N1264	2	Si	100			150 @ 100	1.25	150MA @ 100 @ 25	SAR
1N1265	2	Si	200			150 @ 100	1.25	150MA @ 200 @ 25	SAR
1N1266	2	Si	300			150 @ 100	1.25	150MA @ 300 @ 25	SAR
1N1263A	2	Si	50			200 @ 100	1.25	150MA @ 50 @ 25	SAR
1N1264A	2	Si	100			200 @ 100	1.25	150MA @ 100 @ 25	SAR
1N1265A	2	Si	200			200 @ 100	1.25	150MA @ 200 @ 25	SAR
1N1266A	2	Si	300			200 @ 100	1.25	150MA @ 300 @ 25	SAR
1N1267	2	Si	50			150 @ 100	1.25	150MA @ 50 @ 25	SAR
1N1268	2	Si	100			150 @ 100	1.25	150MA @ 100 @ 25	SAR
1N1269	2	Si	200			150 @ 100	1.25	150MA @ 200 @ 25	SAR
1N1270	2	Si	300			150 @ 100	1.25	150MA @ 300 @ 25	SAR
1N1267A	2	Si	50			200 @ 100	1.25	150MA @ 50 @ 25	SAR
1N1268A	2	Si	100			200 @ 100	1.25	150MA @ 100 @ 25	SAR
1N1269A	2	Si	200			200 @ 100	1.25	150MA @ 200 @ 25	SAR
1N1270A	2	Si	300			200 @ 100	1.25	150MA @ 300 @ 25	SAR
1N1406	1	Si	600	600		.100 @ 75	5.0	25 @ 600 @ 25	INRC
1N1407	1	Si	800	800		.100 @ 75	5.0	25 @ 800 @ 25	INRC
1N1408	1	Si	1000	1000		.100 @ 75	5.0	25 @ 1000 @ 25	INRC
1N1409	1	Si	1200	1200		.100 @ 75	5.0	25 @ 1200 @ 25	INRC
1N1410	1	Si	1500	1500		.100 @ 75	6.25	25 @ 1500 @ 25	INRC
1N1411	1	Si	1800	1800		.100 @ 75	7.5	25 @ 1800 @ 25	INRC
1N1412	1	Si	2000	2000		.100 @ 75	6.25	25 @ 2000 @ 25	INRC
1N1413	1	Si	2400	2400		.100 @ 75	7.5	25 @ 2400 @ 25	INRC
1N1439	2	Si	100			.750 @ 55	1.5	2000 @ 100 @ 25	SAR
1N1440	2	Si	200			.750 @ 55	1.5	2000 @ 200 @ 25	SAR
1N1441	2	Si	300			.750 @ 55	1.5	2000 @ 300 @ 25	SAR
1N1442	2	Si	400			.750 @ 55	1.5	2000 @ 400 @ 25	SAR
1N1445	2	Si	360			.200 @ 25	2.0	4000 @ 360 @ 25	AUD
1N1446	2	Si	100			.750 @ 100	1.4	2000 @ 100 @ 25	AUD
1N1447	2	Si	200			.750 @ 100	1.4	2000 @ 200 @ 25	"
1N1448	2	Si	300			.750 @ 100	1.4	2000 @ 300 @ 25	"
1N1449	2	Si	400			.750 @ 100	1.4	2000 @ 400 @ 25	"
1N1450	2	Si	100			5.0 @ 100	1.4	5000 @ 100 @ 25	"
1N1451	2	Si	200			5.0 @ 100	1.4	5000 @ 200 @ 25	AUD

NOTATIONS

Under Use
1. General Purpose
2. Power Rectifier
3. Magnetic Amplifier

Other
4. For half wave resistive load averaged over 1 cycle

Under Reverse Current
5. Dynamic

Under Mfr.
6. Available in stack form from that manufacturer

Following any temperature reading these symbols apply

A—Ambient
C—Case
J—Junction
S—Storage

Manufacturers should be contacted for value and test condition for surge current and maximum peak recurrent current.

CHARACTERISTICS CHART of DIODES and RECTIFIERS

TYPE NO.	USE (See Code Below)	MAT	PIV (volts)	MAX. CONT. WORK. VOLT. (volts)	Min. Forward Current @ 25°C I_f @ E_f (mA) (volts)	MAX. D.C. OUTPUT CURRENT[4] (amps) @ T (°C)	MAX. FULL LOAD VOLT. DROP[4] (volts)	Max. Rev. Current I_b @ E_b @ T (uA) (volts) (°C)	MFR. (See code at start of charts)
1N1452	2	Si	300			5.0 @ 100	1.4	5000 @ 300 @ 25	"
1N1453	2	Si	400			5.0 @ 100	1.4	5000 @ 400 @ 25	"
1N1454	2	Si	100			25 @ 100	1.5	25 ma @ 100 @ 25	"
1N1455	2	Si	200			25 @ 100	1.5	25 ma @ 200 @ 25	"
1N1456	2	Si	300			25 @ 100	1.5	25 ma @ 300 @ 25	"
1N1457	2	Si	400			25 @ 100	1.5	25 ma @ 400 @ 25	"
1N1458	2	Si	100			35 @ 100	1.5	25 ma @ 100 @ 25	AUD
1N1459	2	Si	200			35 @ 100	1.5	25 ma @ 200 @ 25	"
1N1460	2	Si	300			35 @ 100	1.5	25 ma @ 300 @ 25	"
1N1461	2	Si	400			35 @ 100	1.5	25 ma @ 400 @ 25	"
1N1462	2	Si	100			500 @ 100	1.5	50 ma @ 100 @ 25	"
1N1463	2	Si	200			50 @ 100	1.5	50 ma @ 200 @ 25	"
1N1464	2	Si	300			500 @ 100	1.5	50 ma @ 300 @ 25	"
1N1465	2	Si	400			50 @ 100	1.5	50 ma @ 400 @ 25	AUD
1N1466	2	Si	100			75 @ 100	1.5	50 ma @ 100 @ 25	"
1N1467	2	Si	200			75 @ 100	1.5	50 ma @ 200 @ 25	"
1N1468	2	Si	300			75 @ 100	1.5	50 ma @ 300 @ 25	"
1N1469	2	Si	400			75 @ 100	1.5	50 ma @ 400 @ 25	"
1N1470	2	Si	100			100 @ 100	1.5	100 @ 100 @ 25	AUD
1N1471	2	Si	200			100 @ 100	1.5	100 @ 200 @ 25	"
1N1472	2	Si	300			100 @ 100	1.5	100 @ 300 @ 25	"
1N1473	2	Si	400			100 @ 100	1.5	100 @ 400 @ 25	"
1N1474	2	Si	100			150 @ 100	1.5	100 @ 100 @ 25	"
1N1475	2	Si	200			150 @ 100	1.5	100 @ 200 @ 25	"
1N1476	2	Si	300			150 @ 100	1.5	100 @ 300 @ 25	"
1N1477	2	Si	400			150 @ 100	1.5	100 @ 400 @ 25	"
1N1478	2	Si	100			200 @ 100	1.5	100 @ 100 @ 25	AUD
1N1479	2	Si	200			200 @ 100	1.5	100 @ 200 @ 25	"
1N1480	2	Si	300			200 @ 100	1.5	100 @ 300 @ 25	"
1N1481	2	Si	400			200 @ 100	1.5	100 @ 400 @ 26	"
1N1487	2	Si	100	100		.25 @ 125	0.55	400 @ 100 @ 125	GE
1N1488	2	Si	200	200		.25 @ 125	0.55	300 @ 200 @ 125	GE
1N1489	2	Si	300	300		.25 @ 125	0.55	300 @ 300 @ 125	GE
1N1490	2	Si	400	400		.25 @ 125	0.55	300 @ 400 @ 125	GE
1N1491	2	Si	500	500		.25 @ 110	0.55	300 @ 500 @ 125	GE
1N1492	2	Si	600	600		.25 @ 95	0.55	300 @ 600 @ 125	GE
1N1551	2	Si	100			.750 @ 100	1.4	1 @ 100 @ 100	AUD
1N1552	2	Si	200			.750 @ 100	1.4	1 @ 200 @ 100	AUD
1N1553	2	Si	300			.750 @ 100	1.4	1 @ 300 @ 100	AUD
1N1554	2	Si	400			.750 @ 100	1.4	1 @ 400 @ 100	AUD
1N1555	2	Si	500			.750 @ 100	1.4	1 @ 500 @ 100	AUD
1N1556	2	Si	600			.500 @ 100	1.4	1 @ 100 @ 100	AUD
1N1557	2	Si	200			.500 @ 100	1.4	1 @ 200 @ 100	AUD
1N1558	2	Si	300			.500 @ 100	1.4	1 @ 300 @ 100	AUD
1N1559	2	Si	400			.500 @ 100	1.4	1 @ 400 @ 100	AUD
1N1560	2	Si	500			.500 @ 100	1.4	1 @ 500 @ 100	AUD
1A11	2,3	Si	50	50		.500 @ 40A	1.5	3.0 @ 50 @ 25	FAN
1A12	2,3	Si	100	100		.500 @ 40A	1.5	3.0 @ 100 @ 25	"
1A13	2,3	Si	150	150		.500 @ 40A	1.5	3.0 @ 150 @ 25	"
1A14	2,3	Si	200	200		.500 @ 40A	1.5	3.0 @ 150 @ 25	"
1A15	2,3	Si	250	250		.500 @ 40A	1.5	3.0 @ 150 @ 25	"
1A16	2,3	Si	300	300		.500 @ 40A	1.5	3.0 @ 150 @ 25	"
1A17	2,3	Si	350	350		.500 @ 40A	1.5	3.0 @ 150 @ 25	"
1A18	2,3	Si	400	400		.500 @ 40A	1.5	3.0 @ 150 @ 25	"
2A11	2	Si	50	50		.300 @ 40A	1.5	3.0 @ 50 @ 25	FAN
2A12	2	Si	100	100		.300 @ 40A	1.5	3.0 @ 100 @ 25	"
2A13	2	Si	150	150		.300 @ 40A	1.5	3.0 @ 150 @ 25	"
2A14	2	Si	200	200		.300 @ 40A	1.5	3.0 @ 200 @ 25	"
2A15	2	Si	250	250		.300 @ 40A	1.5	3.0 @ 250 @ 25	"
2A16	2	Si	300	300		.300 @ 40A	1.5	3.0 @ 300 @ 25	"
2A17	2	Si	350	350		.300 @ 40A	1.5	3.0 @ 350 @ 25	"
2A18	2	Si	400	400		.300 @ 40A	1.5	3.0 @ 400 @ 25	"
4JA6011-FH1AA1	2	Si	50			53 @ 35			GE[6]
4JA6011-AH1AA1	2	Si	100			53 @ 35			GE[6]
4JA6011-BH1AA1	2	Si	200			53 @ 35			GE[6]
4JA6011-CH1AA1	2	Si	300			53 @ 35			GE[6]

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AD05H1A1	2	Si	50			1.5 @ 25			AUT[6]
AD10H1A1	2	Si	100			1.5 @ 25			AUT[6]
AD20H1A1	2	Si	200			1.5 @ 25			AUT[6]
AD30H1A1	2	Si	300			1.5 @ 25			AUT[6]
AD40H1A1	2	Si	400			1.5 @ 25			AUT[6]
CTP427	1	Si-Ge	100	80	10 @ .5			75 @ 50 @ 75	CLE
CTP447	1	Si-Ge	25	15	40 @ 1.0			10 @ 10 @ 75	CLE
CTP448	1	Si-Ge	60	50	10 @ .5			25 @ 10 @ 75	CLE
CTP460	1	Si-Ge	20	15	100 @ 1.0			10 @ 10 @ 75	CLE
DR434	1	Ge	40	30	10 @ .37			10 @ 10 @ 25	RRC
DR435	1	Ge	30	20	10 @ .37			10 @ 10 @ 25	RRC
DR668	1	Si	80	70	200 @ 1.0			5 @ 60 @ 150	RRC
DR669	1	Si	150	130	200 @ 1.0			5 @ 125 @ 150	RRC
DR670	1	Si	200	180	200 @ 1.0			5 @ 175 @ 150	RRC
DR671	1	Si	250	225	200 @ 1.0			25 @ 225 @ 150	RRC
G87	1	Ge	50	30	10 @ 1.0			6.0 @ 6 @ 55	GAH
G87B	1	Ge	50	35	10 @ 1.0			32 @ 32 @	GAH
GA53338	2	Si	200			10 @ 105C	1.25	10 @ 200 @ 25	WEC
GA53340	2	Si	200			.500 @ 65A	1.2	2.0 @ 200 @ 25	WEC
HD2762	1	Ge		80	20 @ 1.0			50 @ 50 @ 25	HUG
HD2763	1	Ge		80	20 @ 1.0			100 @ 50 @ 25	HUG
HD2764	1	Ge		80	20 @ 1.0			50 @ 50 @ 25	HUG
HD2765	1	Ge		80	20 @ 1.0			50 @ 50 @ 25	HUG
HR10311	2	Si	500			.200 @ 25		35 @ 450 @ 25	HUG
HR10312	2	Si	600			.200 @ 25		35 @ 550 @ 25	HUG
M14C1	2	Si	100			500 @ 25		10 @ 100 @ 75	MOT
M14C2	2	Si	200			500 @ 25		10 @ 200 @ 75	MOT
M14C3	2	Si	300			500 @ 25		10 @ 300 @ 75	MOT
M14C4	2	Si	400			500 @ 25		10 @ 400 @ 75	MOT
M14C5	2	Si	500			500 @ 25		10 @ 500 @ 75	MOT
M14C6	2	Si	600			500 @ 25		10 @ 600 @ 75	MOT
MA4000	2	Si	50			.200 @ 100	2.0	0.3	MIC
MA4001	2	Si	100			.200 @ 100	2.0	0.3	MIC
MA4002	2	Si	200			.200 @ 100	2.0	0.3	MIC
MA4003	2	Si	300			.200 @ 100	2.0	0.3	MIC
MA4004	2	Si	400			.200 @ 100	2.0	0.3	MIC
MA4005	2	Si	500			.200 @ 100	2.0	0.3	MIC
MA4006	2	Si	600			.200 @ 100	2.0	0.3	MIC
MA4007	2	Si	700			.200 @ 100	2.0	0.3	MIC
MA4008	2	Si	800			.200 @ 100	2.0	0.3	MIC
MA4009	2	Si	50			.400 @ 100	2.0	0.3	MIC
MA4010	2	Si	100			.400 @ 100	2.0	0.3	MIC
MA4011	2	Si	200			.400 @ 100	2.0	0.3	MIC
MA4012	2	Si	300			.400 @ 100	2.0	0.3	MIC
MA4013	2	Si	400			.400 @ 100	2.0	0.3	MIC
MA4014	2	Si	500			.400 @ 100	2.0	0.3	MIC
MA4015	2	Si	600			.400 @ 100	2.0	0.3	MIC
MA4016	2	Si	50			1.000 @ 100	2.0	0.3	MIC
MA4017	2	Si	100			1.000 @ 100	2.0	0.3	MIC
MA4018	2	Si	100			1.000 @ 100	2.0	0.3	MIC
MA4019	2	Si	300			1.000 @ 100	2.0	0.3	MIC
MA4020	2	Si	400			1.000 @ 100	2.0	0.3	MIC
MA4021	2	Si	500			1.000 @ 100	2.0	0.3	MIC
MA4022	2	Si	600			1.000 @ 100	2.0	0.3	MIC
MA4031	2	Si	500			.200 @ 150	2.0	0.5	MIC
MA4032	2	Si	600			.200 @ 150	2.0	0.5	MIC
MA4033	2	Si	50			.400 @ 150	2.0	0.5	MIC
MA4042	2	Si	500			.400 @ 150	2.0	0.5	MIC
MA4043	2	Si	600			.400 @ 150	2.0	0.5	MIC
MA4044	2	Si	50			1.000 @ 150	2.0	0.5	MIC
MA4047	2	Si	200			1.000 @ 150	2.0	0.5	MIC
MA4048	2	Si	300			1.000 @ 150	2.0	0.5	MIC
MA4049	2	Si	400			1.000 @ 150	2.0	0.5	MIC
MA4050	2	Si	500			1.000 @ 150	2.0	0.5	MIC
MA4051	2	Si	600			1.000 @ 150	2.0	0.5	MIC
P0503	2	Si	30	30		5 @ 150	1.2	5 ma 30 @ 25	THE[6]
P0505	2	Si	50	50		5 @ 150	1.2	5 ma 50 @ 25	THE[6]
P0510	2	Si	100	100		5 @ 150	1.2	5 ma 100 @ 25	THE[6]
P0515	2	Si	150	150		5 @ 150	1.2	5 ma 150 @ 25	THE[6]
P0520	2	Si	200	200		5 @ 150	1.2	5 ma 200 @ 25	THE[6]
P0530	2	Si	300	300		5 @ 150	1.2	5 ma 300 @ 25	THE[6]
P0540	2	Si	400	400		5 @ 150	1.2	5 ma 400 @ 25	THE[6]
P1005	2	Si	50	50		10 @ 150	1.2	5 ma 50 @ 25	THE[6]
P1010	2	Si	100	100		10 @ 150	1.2	5 ma 100 @ 25	THE[6]
P1015	2	Si	150	150		10 @ 150	1.2	5 ma 150 @ 25	THE[6]
P1020	2	Si	200	200		10 @ 150	1.2	5 ma 200 @ 25	THE[6]
P1030	2	Si	300	300		10 @ 150	1.2	5 ma 300 @ 25	THE[6]
P1040	2	Si	400	400		10 @ 150	1.2	5 ma 400 @ 25	THE[6]
P1505	2	Si	50	50		15 @ 150	1.2	5 ma 50 @ 25	THE[6]
P1510	2	Si	100	100		15 @ 150	1.2	5 ma 100 @ 25	THE[6]
P1515	2	Si	150	150		15 @ 150	1.2	5 ma 150 @ 25	THE[6]

CHARACTERISTICS CHART of DIODES and RECTIFIERS

TYPE NO.	USE (See Code Below)	MAT	PIV (volts)	MAX. CONT. WORK. VOLT. (volts)	Min. Forward Current @ 25°C: I_f @ E_f (mA) (volts)	MAX. D.C. OUTPUT CURRENT[4] @ T (°C) (amps)	MAX. FULL LOAD VOLT. DROP[4] (volts)	Max. Rev. Current: I_b @ E_b @ T (uA) (volts) (°C)	MFR. (See code at start of charts)
P1520	2	Si	200	200		15 @ 150	1.2	5 ma 200 @ 25	THE[6]
P1530	2	Si	300	300		15 @ 150	1.2	5 ma 400 @ 25	THE[6]
P1540	2	Si	400	400		15 @ 150	1.2	5 ma 300 @ 25	THE[6]
P2005	2	Si	50	50		20 @ 150	1.2	5 ma 50 @ 25	THE[6]
P2010	2	Si	100	100		20 @ 150	1.2	5 ma 100 @ 25	THE[6]
P2015	2	Si	150	150		20 @ 150	1.2	5 ma 150 @ 25	THE[6]
P2020	2	Si	200	200		20 @ 150	1.2	5 ma 200 @ 25	THE[6]
P2030	2	Si	300	300		20 @ 150	1.2	5 ma 300 @ 25	THE[6]
P2040	2	Si	400	400		20 @ 150	1.2	5 ma 400 @ 25	THE[6]
P2505	2	Si	50	50		25 @ 150	1.2	5 ma 50 @ 25	THE[6]
P2510	2	Si	100	100		25 @ 150	1.2	5 ma 100 @ 25	THE[6]
P2515	2	Si	150	150		25 @ 150	1.2	5 ma 150 @ 25	THE[6]
P2520	2	Si	200	200		25 @ 150	1.2	5 ma 200 @ 25	THE[6]
P2530	2	Si	300	300		25 @ 150	1.2	5 ma 300 @ 25	THE[6]
P2540	2	Si	400	400		25 @ 150	1.2	5 ma 400 @ 25	THE[6]
P3005	2	Si	50	50		30 @ 150	1.2	5 ma 50 @ 25	THE[6]
P3010	2	Si	100	100		30 @ 150	1.2	5 ma 100 @ 25	THE[6]
P3015	2	Si	150	150		30 @ 150	1.2	5 ma 150 @ 25	THE[6]
P3020	2	Si	200	200		30 @ 150	1.2	5 ma 200 @ 25	THE[6]
P3030	2	Si	300	300		30 @ 150	1.2	5 ma 300 @ 25	THE[6]
P3040	2	Si	400	400		30 @ 150	1.2	5 ma 400 @ 25	THE[6]
PR100			100		1000 @ 2			20 @ 100	USS
PR200			200		1000 @ 2			20 @ 200	USS
PR300			300		750 @ 2			20 @ 300	USS
PR400			400		750 @ 2			20 @ 400	USS
PR500			500		500 @ 2			20 @ 500	USS
PS050	2	Si	500		100 @ 1.0	.125 @ 100		100 @ 500 @ 100[4,5]	PSI
PS060	2	Si	600		100 @ 1.0	.125 @ 100		100 @ 600 @ 100[4,5]	PSI
PS150	2	Si	500		500 @ 1.5	.150 @ 150	1.5	500 @ 500 @ 150[4,5]	PSI
PS160	2	Si	600		500 @ 1.5	.150 @ 150	1.5	500 @ 500 @ 150[4,5]	PSI
PS405	2	Si	50		500 @ 1.5	.150 @ 150	1.5	500 @ 50 @ 150[4,5]	"
PS410	2	Si	100		500 @ 1.5	.150 @ 150	1.5	500 @ 100 @ 150[4,5]	"
PS415	2	Si	150		500 @ 1.5	.150 @ 150	1.5	500 @ 150 @ 150[4,5]	"
PS420	2	Si	200		500 @ 1.5	.150 @ 150	1.5	500 @ 200 @ 150[4,5]	"
PS425	2	Si	250		500 @ 1.5	.150 @ 150	1.5	500 @ 250 @ 150[4,5]	"
PS430	2	Si	300		500 @ 1.5	.150 @ 150	1.5	500 @ 300 @ 150[4,5]	"
PS435	2	Si	350		500 @ 1.5	.150 @ 150	1.5	500 @ 350 @ 150[4,5]	"
PS440	2	Si	400		500 @ 1.5	.150 @ 150	1.5	500 @ 400 @ 150[4,5]	"
PS450	2	Si	500		500 @ 1.5	.125 @ 150	1.5	500 @ 500 @ 150[4,5]	"
PS460	2	Si	600		500 @ 1.5	.125 @ 150	1.5	500 @ 600 @ 150[4,5]	"
PT505	1	Si	50	50	500 @ 1.5	.5 @ 100		500 @ 50 @ 100[5]	AUT
PT510	1	Si	100	100	500 @ 1.5	.5 @ 100		500 @ 100 @ 100[5]	AUT
PT515	1	Si	150	150	500 @ 1.5	.5 @ 100		500 @ 150 @ 100[5]	AUT
PT520	1	Si	200	200	500 @ 1.5	.5 @ 100		500 @ 200 @ 100[5]	AUT
PT525	1	Si	250	250	500 @ 1.5	.5 @ 100		500 @ 250 @ 100[5]	AUT
PT530	1	Si	300	300	500 @ 1.5	.5 @ 100		500 @ 300 @ 100[5]	AUT
PT540	1	Si	400	400	500 @ 1.5	.5 @ 100		500 @ 400 @ 100[5]	AUT
PT550	1	Si	500	500	500 @ 1.5	.5 @ 100		500 @ 500 @ 100[5]	AUT
R-6.8	1	Si	6.8		50 @ 1.0	.130 @ 25		.5 @ 6.8 @ 25	USS
R-10	1	Si	10		35 @ 1.0	.115 @ 25		.5 @ 10 @ 25	USS
R-15	1	Si	15		23 @ 1.0	.95 @ 25		.5 @ 15 @ 25	USS
R-22	1	Si	22		12 @ 1.0	.75 @ 25		.1 @ 22 @ 25	USS
R-33	1	Si	33		7 @ 1.0	.60 @ 25		.1 @ 33 @ 25	USS
R-47	1	Si	47		4.5 @ 1.0	.45 @ 25		.1 @ 47 @ 25	USS
R-68	1	Si	68		2.7 @ 1.0	.36 @ 25		1.0 @ 68 @ 25	USS
R-100	1	Si	100		1.5 @ 1.0	.25 @ 25		1.0 @ 100 @ 25	USS
R-150	1	Si	150		1.0 @ 1.0	.17 @ 25		3.0 @ 150 @ 25	USS
R-220	1	Si	220		6.5 @ 4.0	.14 @ 25		5.0 @ 220 @ 25	USS
R-330	1	Si	330		3.0 @ 4.0	.12 @ 25		5.0 @ 330 @ 25	USS
R-470	1	Si	470		2.0 @ 4.0	.10 @ 25		5.0 @ 470 @ 25	USS
TM84	2	Si	800	800	2000 @ 2.0	1.0 @ 125C	2.0	500 @ @ 125C[5]	TRA[6]
TM85	2	Si	800	800	800 @ 2.0	.400 @ 125C	2.0	500 @ @ 125C[5]	TRA[6]
TM104	2	Si	1000	1000	2000 @ 2.0	1.0 @ 125C	2.0	500 @ @ 125C[5]	TRA[6]
TM105	2	Si	1000	1000	800 @ 2.0	.400 @ 125C	2.0	500 @ @ 125C[5]	TRA[6]
VA713A	2	Ge	160			13 @ 35A			EEVB
VA713B	2	Ge	140			13 @ 35A			"
VA713C	2	Ge	120			13 @ 35A			"
VA713D	2	Ge	100			13 @ 35A			"
VA713E	2	Ge	80			13 @ 35A			"
VA713F	2	Ge	60			13 @ 35A			"
VA713G	2	Ge	40			13 @ 35A			"
VA713H	2	Ge	20			13 @ 35A			"
VA718A	2	Ge	160			3.75 @ 35A			"
VA718B	2	Ge	140			3.75 @ 35A			"
VA718C	2	Ge	120			3.75 @ 35A			"
VA718D	2	Ge	100			3.75 @ 35A			"
VA718E	2	Ge	80			3.75 @ 35A			"
VA718F	2	Ge	60			3.75 @ 35A			"
VA718G	2	Ge	40			3.75 @ 35A			"
VA718H	2	Ge	20			3.75 @ 35A			"
X-403	2	Si	250			.25 @ 25A	1.5	100 @ 200 @	BEN

CHARACTERISTICS CHART of SILICON ZENER or AVALANCHE DIODES

TYPE NO.	Zener or Avalanche Voltage Range MIN. Eb1 (volts)	MAX. Eb2 (volts)	@ Iz (ma)	Dynamic Impedance Z (ohms)	@ Iz (ma)	MAX. DISS. (mw)	TEMP. CO-EF-FICIENT %/°C	MFR. {See code at start of chart}
1N1351A	9.5	10.5	500	2.0	500	10W	.06	HSD
1N1352A	10.45	11.55	500	2.0	500	10W	.06	HSD
1N1353A	11.4	12.6	500	2.0	500	10W	.06	HSD
1N1354A	12.35	13.65	500	2.0	500	10W	.07	HSD
1N1355A	14.25	15.75	500	2.0	500	10W	.07	HSD
1N1356A	15.2	16.8	500	3.0	500	10W	.07	HSD
1N1357A	17.1	18.9	500	3.0	500	10W	.07	HSD
1N1358A	19.0	21.0	150	3.0	150	10W	.08	HSD
1N1359A	20.9	23.1	150	3.0	150	10W	.08	HSD
1N1360A	22.8	25.6	150	3.0	150	10W	.08	HSD
1N1361A	25.65	28.35	150	3.0	150	10W	.08	HSD
1N1362A	28.5	31.5	150	4.0	150	10W	.08	HSD
1N1363A	31.35	34.65	150	4.0	150	10W	.08	HSD
1N1364A	34.2	37.8	150	5.0	150	10W	.09	HSD
1N1365A	37.05	40.95	150	5.0	150	10W	.09	HSD
1N1366A	40.85	45.15	150	6.0	150	10W	.09	HSD
1N1367A	44.65	49.35	150	7.0	150	10W	.09	HSD
1N1368A	48.45	53.55	150	8.0	150	10W	.10	HSD
1N1369A	53.2	58.8	150	9.0	150	10W	.10	HSD
1N1370A	58.9	65.1	50	12	50	10W	.10	HSD
1N1371A	64.6	71.4	50	14	50	10W	.10	HSD
1N1372A	71.25	78.75	50	20	50	10W	.11	HSD
1N1373A	77.9	86.1	50	22	50	10W	.11	HSD
1N1374A	86.45	95.55	50	35	50	10W	.12	HSD
1N1375A	95.0	105	50	40	50	10W	.12	HSD
3Z3.9	3.6	4.3	850	.50	150	3500	.04	INRC
3Z4.7	4.3	5.1	700	.50	125	3500	.00	"
3Z5.6	5.1	6.2	625	.75	110	3500	.03	"
3Z6.8	6.2	7.5	525	1.0	100	3500	.05	"
3Z8.2	7.5	9.1	425	1.5	80	3500	.06	"
3Z10	9.1	11.0	350	2.5	70	3500	.07	"
3Z12	11.0	13.0	275	4.0	50	3500	.075	"
3Z15	13.0	16.0	225	7.5	40	3500	.08	"
3Z18	16.0	20.0	200	15	35	3500	.085	"
3Z22	20.0	24.0	160	22.5	30	3500	.09	"
3Z27	24.0	30.0	125	30	25	3500	.095	"
10Z3.9	3.6	4.3	2500	.25	500	10W	.04	"
10Z4.7	4.3	5.1	2000	.25	400	10W	.00	"
10Z5.6	5.1	6.2	1750	.40	350	10W	.03	"
10Z6.8	6.2	7.5	1500	.50	300	10W	.05	"
10Z8.2	7.5	9.1	1200	.75	250	10W	.06	INRC
10Z10	9.1	11.0	1000	1.25	200	10W	.07	"
10Z12	11.0	13.0	850	2.0	170	10W	.075	"
10Z15	13.0	16.0	650	4.0	140	10W	.08	"
10Z18	16.0	20.0	550	7.5	110	10W	.085	"
10Z22	20.0	24.0	450	12	90	10W	.09	"
10Z30	24.0	30.0	350	15	70	10W	.095	"
650C0	3.52	3.89	5.0			150	.045	TII
650C1	3.61	3.99	5.0			150	.042	TII
650C2	3.71	4.10	5.0			150	.040	TII
650C3	3.80	4.20	5.0			150	.040	TII
650C4	3.90	4.31	5.0			150	.039	TII
650C5	3.99	4.41	5.0			150	.038	TII
650C6	4.09	4.52	5.0			150	.035	TII
650C7	4.18	4.62	5.0			150	.032	TII
651C0	4.28	4.73	5.0			150	.030	TII
651C1	4.37	4.83	5.0			150	.028	TII
651C2	4.47	4.94	5.0			150	.026	TII
651C3	4.56	5.04	5.0			150	.024	TII
651C4	4.66	5.15	5.0			150	.022	TII
651C5	4.75	5.25	5.0			150	.018	TII
651C6	4.85	5.36	5.0			150	.014	TII
651C7	4.94	5.46	5.0			150	.010	TII
651C8	5.04	5.57	5.0			150	.007	TII
651C9	5.13	5.67	5.0			150	.002	TII
652C0	5.23	5.78	5.0			150	.000	TII
652C1	5.32	5.88	5.0			150	.002	TII
652C2	5.42	5.99	5.0			150	.006	TII
652C3	5.51	6.09	5.0			150	.010	TII
652C4	5.61	6.20	5.0			150	.015	TII
652C5	5.70	6.30	5.0			150	.019	TII
652C6	5.80	6.41	5.0			150	.021	TII
652C7	5.89	6.51	5.0			150	.024	TII
652C8	5.99	6.62	5.0			150	.027	TII
652C9	6.08	6.72	5.0			150	.030	TII
653C0	6.18	6.83	5.0			150	.032	TII
653C1	6.27	6.93	5.0			150	.034	TII
653C2	6.37	7.04	5.0			150	.036	TII
653C3	6.46	7.14	5.0			150	.038	TII
653C4	6.65	7.35	5.0			150	.041	TII
653C5	6.84	7.56	5.0			150	.043	TII
653C6	7.03	7.71	5.0			150	.046	TII

NOTATIONS

Under Type No.

1. Double Anode Types
* Developmental Types

CHARACTERISTICS CHART of SILICON ZENER or AVALANCHE DIODES

TYPE NO.	Zener or Avalanche Voltage Range MIN. Eb1 (volts)	MAX. Eb2 (volts)	@ Iz (ma)	Dynamic Impedance Z @ Iz (ohms)	(ma)	MAX. DISS. (mw)	TEMP. CO-EF-FICIENT %/°C	MFR. (See code at start of chart)
653C7	7.22	7.98	5.0			150	.049	TII
653C8	7.41	8.19	5.0			150	.050	TII
653C9	7.60	8.40	5.0			150	.050	TII
GA53339-3	7.38	9.02	10			3000		WEC*
GA53339-4	10.8	13.2	10			3000		WEC*
GA53339-5	13.5	16.5	10			3000		WEC*
GA53339-6	16.2	19.8	10			3000		WEC*
GA53339-7	19.8	24.2	10	20	10	3000	.080	WEC*
GA53339-8	26.3	29.7	10	25	10	3000	.085	WEC*
GA53339-9	61.2	74.8	10	50	10	3000	.095	WEC*
GA53339-10	90	110	10			3000		WEC*
GA53339-11	135	165	10	300	10	3000	.10	WEC*
GA53341-3	7.38	9.02	10	15	10	500		WEC*
GA53341-4	10.8	13.2	2.0	15	2.0	500		WEC*
GA53341-5	13.5	16.5	2.0	20	2.0	500		WEC*
GA53341-6	16.2	19.8	2.0	25	2.0	500		WEC*
GA53341-7	19.8	24.2	2.0	30	2.0	500	.08	WEC*
GA53341-8	26.3	29.7	2.0	35	2.0	500	.085	WEC*
GA53341-9	61.2	74.8	.50	100	.50	500	.095	WEC*
GA53341-10	90	110	.50	200	.50	500		WEC*
GA53341-11	135	165	.50	340	.50	500	.10	WEC*
GA53342-2	5.58	6.82	10			100		WEC*
GA53342-3	7.38	9.02	10			100		WEC*
GA53342-4	10.8	13.2	10			100		WEC*
GA53342-5	13.5	16.5	2.0			100		WEC*
GA53342-6	16.2	19.8	2.0			100		WEC*
GA53342-7	19.8	24.2	2.0			100		WEC*
GA53342-8	26.3	29.7	2.0			100		WEC*
GA53342-9	61.2	74.8	.50			100		WEC*
GA53342-10	90	110	.50			100		WEC*
GA53342-11	135	165	.50			100		WEC*
HZ27	24.0	30.0	200	7.0	40	5000	.00	INRC
HZ33	30.0	36.0	150	10	30	5000	.03	"
HZ47	43.0	51.0	110	20	22	5000	.06	"
HZ68	62.0	75.0	75	60	14	5000	.075	"
HZ100	91.0	110	50	180	10	5000	.085	"
HZ150	130	160	35	370	7.0	5000	.095	"
IZ3.9	3.6	4.3	250	1.0	50	1000	.04	"
IZ4.7	4.3	5.1	200	1.0	40	1000	.00	"
IZ5.6	5.1	6.2	175	1.5	35	1000	.03	"
IZ6.8	6.2	7.5	150	2.0	30	1000	.05	"
IZ8.2	7.5	9.1	120	3.0	25	1000	.06	"
IZ10	9.1	11.0	100	4.5	20	1000	.07	"
IZ12	11.0	13.0	80	7.5	45	1000	.075	"
IZ15	13.0	16.0	65	15	13	1000	.08	"
IZ18	16.0	20.0	55	30	10	1000	.085	"
IZ22	20.0	24.0	45	45	9.0	1000	.09	"
IZ27	24.0	30.0	35	60	7.0	1000	.095	"
LZ-3.9	3.6	4.3	5	25	20	400	.07	USS
LZ-4.7	4.3	5.1	5	20	20	400	.05	USS
LZ-5.6	5.1	6.2	5	7.5	20	400	.04	USS
LZ-6.8	6.2	7.5	5	7.5	20	400	.01	USS
LZ-8.2	7.5	9.1	5	20	20	400	.02	USS
LZ-10	9.1	11.0	5	45	20	400	.03	USS
LZ-12	11	13	1	65	20	400	.045	USS
LZ-15	13	16	1	95	10	400	.065	USS
LZ-18	16	20	1	145	10	400	.08	USS
LZ-22	20	24	1	195	10	400	.085	USS
LZ-27	24	30	1	290	10	400	.09	USS
LZ-33	30	36	.2	350	5	400	.095	USS
LZ-39	36	43	.2	550	5	400	.1	USS
LZ-47	43	51	.2	750	5	400		USS
LZ-56	51	62	.2	1000	5	400		USS
LZ-68	62	75	.2			400		USS
LZ-82	75	91	.2			400		USS
LZ-100	91	110	.2			400		USS
MZ3.9	3.6	4.3	125	1.5	20	500	.00	INRC
MZ4.7	4.3	5.1	100	1.5	20	500	.00	"
MZ5.6	5.1	6.2	90	2.3	17.5	500	.03	INRC
MZ6.8	6.2	7.5	75	3.0	15	500	.05	"
MZ8.2	7.5	9.1	60	4.5	12.5	500	.06	"
MZ10	9.1	11.0	50	6.8	10	500	.07	"
MZ12	11.0	13.0	40	12	7.5	500	.075	"
MZ15	13.0	16.0	33	23	6.0	500	.08	"
MZ18	16.0	20.0	27	45	5.0	500	.085	"
MZ22	20.0	24.0	23	70	4.5	500	.09	"
MZ27	24.0	30.0	18	90	3.5	500	.095	"
SV6	5.2	6.4	10	20	10	250	.02	TRA
SV9	7.5	10.0	10	15	10	250	.055	TRA
SV13	11.0	14.5	5.0	70	5.0	250	.07	TRA
SV18	17.0	21.0	5.0	200	5.0	250	.08	TRA
SV121	4.28	4.73	10	55	10	250	.02	TRA
SV122	4.75	5.25	10	55	10	250	.00	TRA

NOTATIONS

Under Type No.

1. Double Anode Types
* Developmental Types

TYPE NO.	Zener or Avalanche Voltage Range MIN. Eb1 (volts)	MAX. Eb2 (volts)	@ Iz (ma)	Dynamic Impedance Z @ Iz (ohms)	(ma)	MAX. DISS. (mw)	TEMP. CO-EF-FICIENT %/°C	MFR. (See code at start of chart)
SV123	5.23	5.78	10	20	10	250	.015	TRA
SV124	5.70	6.30	10	20	10	250	.03	TRA
SV125	6.18	6.83	10	8	10	250	.038	TRA
SV126	6.65	7.35	10	8	10	250	.043	TRA
SV127	7.13	7.88	10	8	10	250	.047	TRA
SV128	7.60	8.40	10	15	10	250	.05	TRA
SV129	8.08	8.93	10	15	10	250	.054	TRA
SV131	8.55	9.45	10	15	10	250	.057	TRA
SV132	9.04	9.98	10	15	10	250	.058	TRA
SV133	9.5	10.5	5.0	50	5.0	250	.06	TRA
SV134	10.45	11.55	5.0	50	5.0	250	.063	TRA
SV135	11.4	12.6	5.0	70	5.0	250	.066	TRA
SV136	12.35	13.65	5.0	70	5.0	250	.069	TRA
SV137	13.3	14.7	5.0	70	5.0	250	.072	TRA
SV138	14.25	15.75	5.0	120	5.0	250	.075	TRA
SV139	15.2	16.8	5.0	120	5.0	250	.076	TRA
SV141	16.15	17.85	5.0	120	5.0	250	.077	TRA
SV142	17.1	18.9	5.0	200	5.0	250	.078	TRA
SV143	18.05	19.95	5.0	200	5.0	250	.079	TRA
SV144	19.0	21.0	5.0	200	5.0	250	.081	TRA
SV168	20.9	23.1	5.0	300	5.0	250	.084	TRA
SV169	22.8	25.2	5.0	300	5.0	250	.086	TRA
SV171	24.7	27.3	5.0	300	5.0	250	.088	TRA
SV805	5.2	6.4	10	20	10	750	.02	TRA
SV808	7.5	10.0	10	15	10	750	.055	TRA
SV812	11.0	14.5	5.0	70	5.0	750	.07	TRA
SV818	17.0	21.0	5.0	200	5.0	750	.08	TRA
SV905	5.2	6.4	1000	.70	1000	10W	.02	TRA
SV908	7.5	10.0	1000	.80	1000	10W	.055	TRA
SV912	11.0	14.5	500	2.0	500	10W	.07	TRA
SV918	17.0	21.0	500	3.0	500	10W	.08	TRA
SV1004	4.28	4.73	10	55	10	750	.02	TRA
SV1005	4.75	5.25	10	55	10	750	.00	TRA
SV1006	5.23	5.78	10	20	10	750	.015	TRA
SV1007	5.70	6.30	10	20	10	750	.03	TRA
SV1008	6.18	6.83	10	8	10	750	.038	TRA
SV1009	6.65	7.35	10	8	10	750	.043	TRA
SV1010	7.13	7.88	10	8	10	750	.047	TRA
SV1011	7.60	8.40	10	15	10	750	.05	TRA
SV1012	8.08	8.93	10	15	10	750	.054	TRA
SV1013	8.55	9.45	10	15	10	750	.057	TRA
SV1014	9.04	9.98	10	15	10	750	.058	TRA
SV1015	9.5	10.5	5.0	50	5.0	750	.06	TRA
SV1016	10.45	11.55	5.0	50	5.0	750	.063	TRA
SV1017	11.4	12.6	5.0	70	5.0	750	.066	TRA
SV1018	12.35	13.65	5.0	70	5.0	750	.069	TRA
SV1019	13.3	14.7	5.0	70	5.0	750	.072	TRA
SV1020	14.25	15.75	5.0	120	5.0	750	.075	TRA
SV1021	15.2	16.8	5.0	120	5.0	750	.076	TRA
SV1022	16.15	17.85	5.0	120	5.0	750	.077	TRA
SV1023	17.1	18.9	5.0	200	5.0	750	.078	TRA
SV1024	18.05	19.95	5.0	200	5.0	750	.079	TRA
SV1025	19.0	21.0	5.0	200	5.0	750	.081	TRA
SV1033	20.9	23.1	5.0	300	5.0	750	.084	TRA
SV1034	22.8	25.2	5.0	300	5.0	750	.086	TRA
SV1035	24.7	27.3	5.0	300	5.0	750	.088	TRA
SV2004	4.28	4.73	1000	.50	1000	10W	.02	TRA
SV2005	4.75	5.25	1000	.50	1000	10W	.00	TRA
SV2006	5.23	5.78	1000	.70	1000	10W	.015	TRA
SV2007	5.70	6.30	1000	.70	1000	10W	.03	TRA
SV2008	6.18	6.83	1000	.80	1000	10W	.038	TRA
SV2009	6.65	7.35	1000	.80	1000	10W	.043	TRA
SV2010	7.13	7.88	1000	.80	1000	10W	.047	TRA
SV2011	7.60	8.40	1000	.80	1000	10W	.05	TRA
SV2012	8.08	8.93	1000	.80	1000	10W	.054	TRA
SV2013	8.55	9.45	1000	.80	1000	10W	.057	TRA
SV2014	9.04	9.98	1000	.80	1000	10W	.058	TRA
SV2015	9.5	10.5	500	1.5	500	10W	.06	TRA
SV2016	10.45	11.55	500	1.5	500	10W	.063	TRA
SV2017	11.4	12.6	500	2.0	500	10W	.066	TRA
SV2018	12.35	13.65	500	2.0	500	10W	.069	TRA
SV2019	13.3	14.7	500	2.0	500	10W	.072	TRA
SV2020	14.24	15.75	500	3.0	500	10W	.075	TRA
SV2021	15.2	16.8	500	3.0	500	10W	.076	TRA
SV2022	16.15	17.85	500	3.0	500	10W	.077	TRA
SV2023	17.1	18.9	500	3.0	500	10W	.078	TRA
SV2024	18.05	19.95	500	3.0	500	10W	.079	TRA
SV2025	19.0	21.0	500	3.0	500	10W	.081	TRA
SV2044	20.9	23.1	150	8.0	150	10W	.084	TRA
SV2045	22.8	25.2	150	8.0	150	10W	.086	TRA
SV2046	24.7	27.3	150	8.0	150	10W	.088	TRA
Z-3.9	3.6	4.3	5	30	10	150	.07	USS
Z-4.7	4.3	5.1	5	25	10	150	.04	USS
Z-5.6	5.1	6.2	5	10	10	150	.01	USS
Z-6.8	6.2	7.5	5	10	10	150	.01	USS

NOTATIONS

Under Type No.

1. Double Anode Types
* Developmental Types

CHARACTERISTICS CHART of SILICON ZENER or AVALANCHE DIODES

TYPE NO.	Zener or Avalanche Voltage Range MIN. E_{b1} (volts)	MAX. E_{b2} (volts)	@ I_z (ma)	Dynamic Impedance Z @ I_z (ohms)	(ma)	MAX. DISS. (mw)	TEMP. CO-EF-FICIENT %/°C	MFR. {See code at start of chart}
Z-8.2	7.5	9.1	5	25	10	150	.02	USS
Z-10	9.1	11.0	5	50	10	150	.03	USS
Z-12	11	13	1	70	10	150	.045	USS
Z-15	13	16	1	100	5	150	.065	USS
Z-18	16	20	1	150	5	150	.08	USS
Z-22	20	24	1	200	5	150	.085	USS
Z-27	24	30	1	300	5	150	.09	USS
Z-33	30	36	.2	400	1	150	.095	USS
Z-39	36	43	.2	600	1	150	.1	USS
Z-47	43	51	.2	800	1	150		USS
Z-56	51	62	.2	1000	1	150		USS
Z-68	62	75	.2			150		USS
Z-82	75	91	.2			150		USS
Z-100	91	110	.2			150		USS
Z-120	110	130	.2			150		USS
Z-150	130	160	.1			150		USS
Z-180	160	200	.1			150		USS
Z-220	200	240	.1			150		USS
Z-270	240	300	.1			150		USS
Z-330	300	360	.1			150		USS
Z-390	360	430	.1			150		USS
Z-470	430	510	.1			150		USS
Z-560	510	620	.1			150		USS
ZT-3.9	3.6	4.3	5	30	10	200	.06	USS
ZT-4.7	4.3	5.1	5	25	10	200	.04	USS
ZT-5.6	5.1	6.2	5	10	10	200	.01	USS
ZT-6.8	6.2	7.5	5	10	10	200	.01	USS
ZT-8.2	7.5	9.1	5	25	10	200	.02	USS
ZT-10	9.1	11.0	5	50	10	200	.025	USS
ZT-12	11	13	1	70	10	200	.04	USS
ZT-15	13	16	1	100	5	200	.06	USS
ZT-18	16	20	1	150	5	200	.07	USS
ZT-22	20	24	1	200	5	200	.085	USS
ZZ3.9	3.6	4.3	110	3.0	22	350	.045	INRC
ZZ4.7	4.3	5.1	90	4.0	18	350	.01	"
ZZ5.6	5.1	6.2	70	5.0	14	350	.00	"
ZZ6.8	6.2	7.5	60	10	12	350	.025	"
ZZ8.2	7.5	9.1	50	15	10	350	.035	"
ZZ10	9.1	11.0	40	25	8.0	350	.05	"
ZZ12	11.0	13.0	30	40	7.5	350	.06	"
ZZ15	13.0	16.0	25	60	5.0	350	.07	"
ZZ18	16.0	20.0	20	80	4.0	350	.08	"
ZZ22	20.0	24.0	16	125	3.5	350	.09	"
ZZ27	24.0	30.0	13	200	3.0	350	.095	"

NOTATIONS

Under Type No.

1. Double Anode Types
* Developmental Types

CHARACTERISTICS CHART of SWITCHING DIODES

TYPE NO.	MAT	PIV (volts)	MAX. CONT. REV. WORK. VOLT. (volts)	Min. Forward Current @ 25°C I_f @ E_f (mA) (volts)	Reverse Impedance @ 25°C Z (K ohms)	VOLTAGE RANGE E_{b1} to E_{b2} (volts)	Recovery Characteristics TEST CONDITIONS Fwd. Rev. I_f to E_b (ma) (volts)	$Z_{rec.}$ @ time (t) (K ohms) (usec)	MFR. {See code at start of charts}
1N625	Si		30	4.0 @ 1.5	2000	20		15 @ .15	HUG, PSI, TRA, RRC
1N626	Si		50	4.0 @ 1.5	1750	35		400 @ 1.0	HUG, PSI, TRA, RRC
1N627	Si		100	4.0 @ 1.5	3000	75		400 @ 1.0	HUG, PSI, TRA, RRC
1N628	Si		150	4.0 @ 1.5	6250	125		400 @ 1.0	HUG, PSI, TRA, RRC
1N629	Si		200	4.0 @ 1.5	8750	175		400 @ 1.0	HUG, PSI, TRA, RRC
1N658	Si	120	100	100 @ 1.0	1000M	50	5 to 40	80 @ .30	RRC
1N662	Si		80	10 @ 1.0	2500	50	5 to 40	100 @ .50	PSI
1N663	Si		80	100 @ 1.0	15000	75	5 to 40	200 @ .50	PSI
DR672	Si	50	35	100 @ 1.0	70M	35	5 to 40	400 @ 1.0	RRC
DR673	Si	100	75	100 @ 1.0	150M	75	5 to 40	400 @ 1.0	RRC
DR674	Si	150	125	100 @ 1.0	250M	125	5 to 40	400 @ 1.0	RRC
DR675	Si	200	175	100 @ 1.0	350M	175	5 to 40	400 @ 1.0	RRC
DR677	Si	30	20	100 @ 1.0	40M	20	5 to 20	15 @ .15	RRC
HD6573	Si		150	6.0 @ 1.5	1250	125		400 @ 1.0	HUG
HD6635	Si		50	15 @ 1.5	1750	35		400 @ 1.0	HUG
HD6641	Si		150	15 @ 1.5	6250	125		400 @ 1.0	HUG
HD6642	Si		50	6.0 @ 1.5	1750	35		400 @ 1.0	HUG
LD-105		105	80	100 @ 1.0			5 to 40	50 @ 0.3	CBS
LD-106		53	35	100 @ 0.7			150 to 0.83	@ 0.6	CBS
LD-107		65	50	100 @ 1.0	860	48	30 to 35	20 @ 1.0	CBS

CHARACTERISTICS CHART of MISCELLANEOUS DIODE TYPES

TYPE NO.	CLASSIFI-CATION	DESCRIPTION	MFR.
1N21WE	1, 2	Military version 1N21E (reversible)	MIC
1N23WE	1, 2	Military version 1N23E (reversible)	MIC
1N77B	4	Sensitivity-28 peak to peak volts Reverse I-Dark 15μa @ 10V Freq. response-15KC	SYL
1N147	2	UHF Mixer up to 1000 MC.; PIV—2 V; Av. DC—25 ma; Pk DC—55 ma; 0-70°C temp. range; 10 db N.F. @ 500 MC	PHI
1N173A	2	UHF Mixer up to 1000 MC; same current & voltage ratings as 1N147; —40° C to 70° C temp. range; 12.5 db maximum overall N.F; ceramic, moisture proof case.	PHI
1N263	1, 2	Low noise mixer up to 12 KMC, specially suited for X-band, PIV—1.0 V, PK. DC-50 ma Pk. power—1 watt, 150°C max oper. temp; 6 db conversion loss and 7.5 db max. overall NF @ 9375 MC, electrically symmetrical for balanced mixer operation.	PHI
4N20D	7	Breakdown—15 to 25V @ .5 ma max Holding—2V. max @ 50 ma max	SSL
4N30D	7	Breakdown—25 to 35V & .5 ma. max Holding—2V max & 50 ma max	SSL
4N40D	7	Breakdown—35 to 45V & .5 ma. max Holding—2V max & 50 ma max	SSL
4N50D	7	Breakdown—45 to 55V & .5 ma max Holding—2V max & 50 ma max.	SSL
LD-31		TV Automatic Fine Tuning I_b —50 ma min. at +1.0 V & 25° C.	CBS
		LI_b —20 μa max. at —20 V & 25° C.	
LD-38	2	High Temp. Video Det. I_b —0.5 ma min. at +0.60 V & 25° C.	CBS
		LI_b —150 μa max. at —27 V. & 70° C.	
MA421A	1, 2	6.5 DB Overall Noise Fig. mixer diode UHF-4000 MC/S	MIC
MA421B	1, 2	6.0 DB overall noise figure mixer diode—UHF—4000 MC/S	MIC
MA423A	1, 2	mixer diode 4000—10,000 MC/S	MIC
MA424	1	Test equipment diode for power monitoring purposes through 10,000 MC/S upper limit	MIC
MA425	1	Reversible polarity MA-424	MIC
MA428	1, 2	Very low noise figure mixer and video diode for 50-75 KMC band	MIC
MA430	1	Equivalent to the 1N21C for high temp. operation to 150° C	MIC
MA431	1	Equivalent to the 1N23C for high temp. operation to 150° C	MIC
OA70	2	Video detector up to 100 MC. PIV—22. 5V., max If—50 ma	MUL
TP50	4	Sensitivity 30 ma./Lumen dark current—3.5 μa max; max working voltage —100 V.	NPC

OTATIONS

nder Classification

Microwave Diodes
Mixer or Detector Diodes
Variable Capacitor Diodes

4. Photodiodes
5. Solar Cells
6. Harmonic Generator Diodes
7. 4-Layer Bistable Diode

THE FOLLOWING MANUFACTURERS HAVE ANNOUNCED THAT THEY HAVE JUST BEGUN SUPPLYING THE INDICATED PREVIOUSLY REGISTERED DIODES AND RECTIFIERS

UTOMATIC MFG: 1N445B, 1N547, 1N613A, 1N614A, 1N1096

AHAGAN: 1N39A 1N51, 1N55A, 1N58, 1N59, 1N61, 1N67, 1N69, 1N95, 1N126, 1N128, 1N298

ENERAL ELECTRIC: 1N256, IN445, 1N445B. The 1N91, 1N92, 1N93, 1N536, 1N537, 1N538, 1N539, 1N540, 1N1095 are now available as Octal-Socket Potted Rectifier Circuits and are designated as the 4JA220 series (1N91, 1N92, 1N93) and the others as the 4JA420 ries.

ITERNATIONAL RECTIFIER CORP: 1N253, 1N254, 1N255, 1N256, 1N332, 1N333, 1N334, 1N335, 1N336, 1N337, 1N339, 1N340, 1N341, N342, 1N343, 1N344, 1N345, 1N346, 1N348, 1N349, 1N440, 1N440B, 1N441, 1N441B, 1N442, 1N442B, 1N443, 1N443B, 1N444, 1N444B, N445, 1N536, 1N537, 1N538, 1N539, 1N540, 1N1100, 1N1101, 1N1102, 1N1103

ICROWAVE ASSOCIATES: 1N253, 1N254, 1N255, 1N256, 1N332, 1N333, 1N334, 1N335, 1N336, 1N337, 1N338, 1N339, 1N340, 1N341, N342, 1N343, 1N344, 1N345, 1N346, 1N347, 1N348, 1N349

ACIFIC SEMICONDUCTORS, INC: 1N645, 1N646, 1N647, 1N648, 1N649

ADIO RECEPTOR: 1N34, 1N34A, 1N38, 1N38A, 1N48, 1N51, 1N52, 1N54, 1N54A, 1N55, 1N55A, 1N55B, 1N56, 1N56A, N58, 1N58A, 1N63, 1N67A, 1N68A, 1N69, 1N70, 1N81, 1N89, 1N90, 1N95, 1N96, 1N97A, 1N98A, 1N99A, 1N100A, N116A, 1N117A, 1N118A, 1N126, 1N127, 1N128, 1N191, 1N192, 1N198, 1N281, 1N456, 1N457, 1N458, 1N459, 1N461, N462, 1N463, 1N464, 1N482, 1N482A, 1N482B, 1N483, IN483A, 1N483B, 1N484, 1N484A, 1N484B, 1N485, 1N485A, 1N485B, N486, 1N486A

YLVANIA: 1N63, 1N140, 1N283, 1N636

RANSITRON: 1N440B, 1N441B, 1N442B, 1N443B, 1N444B, 1N536, 1N537, 1N538, 1N539, 1N540, 1N560, 1N561, 1N599, 1N599A, 1N600, N600A, 1N601, 1N601A, 1N602, 1N602A, 1N603, 1N603A, 1N604, 1N604A, 1N605, 1N605A, 1N606, 1N606A, 1N645, 1N646, 1N647, N648, 1N649, 1N1095

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Ultrasonic Cleaning Reduces Diode Failure

MICHAEL C. TAMAS*

To the manufacturer of electronic equipment, the tiniest speck of dust can be the biggest trouble-maker. This is particularly true in the case of diode production, where a dust particle might cause a leaky seal between glass-to-glass or glass-to-metal bonds, or where it might later cause contamination of the highly pure silicon wafer.

The best remedy, of course, is to carry on all production in "white" rooms, where the air is constantly filtered, where only lintless clothing is permitted, and where any number of other precautionary steps are taken. However, despite all these efforts, some dust is inevitable, so that components must be carefully cleaned and inspected before being assembled.

After investigating several approaches, one company[1] found that ultrasonic cleaning provides a sure

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Branson Ultrasonic Corp.

[1]Semiconductor Division, Sperry Rand Corp.

Fig. 1—If any residue is left in joint line between glass bead and copper wire it will contaminate silicon disk in diode. Sonogen generator, atop hood, and ultrasonic transducer, on table, remove all traces of borate residue in less than one minute, have considerably reduced rejects. Ultrasonic energy is transmitted from transducer in bottom of tank, through liquid in tank, into cleaning solution in beaker. Fine-mesh stainless steel basket holds beaded wires.

thod of decontaminating the mi-te parts they have to handle. Not ly does this high-speed agitation move all surface soil, but it also ocks out loose chips in the glass eves they use, and it is ideal for noving the last traces of a borated ating needed in glass-beading met wires.

In production an eight-station ntable carries batches of beaded res through an alkaline etch, fol-ved by five rinses. At the last sta-n, the wires are automatically re-oved from the carrier, and dropped wn a chute into a waiting re-ptacle.

The alkaline etch removes all the rated coating from the wire, ex-pt for a flaky residue usually left the corner of the glass-metal int. In the past, there was no way remove it without undercutting e seal, yet it simply had to come f. Otherwise the residue would rtainly ruin the diode, because it ntaminates the silicon wafer dur-g the subsequent high-tempera-re fusing operation.

This annoying problem has now en solved through the use of ultra-nic cleaning equipment. After the kaline etch, several hundred eaded wires are placed into a small ainless steel 0.022-mesh basket, bjected to an ultrasonic bath at ° C for 3 minutes, then continually ished with demineralized water til readings of the rinse water in-cate that no further impurities are eing removed.

Figures 1 and 2 show the cleaning t-up. The ultrasonic generator is

g. 2—Fine-mesh stainless steel sket holds about 200 beaded ires, all cleaned in a minute in trasonic bath. Note ripples on sur-ce of beaker, visible signs of ultra-nic energy in cleaning fluid. intless white gloves, smocks, and ps are worn as another step toward e utmost in cleanliness.

atop the hood, and the tank/transducer combination which converts the high-frequency electrical energy into mechanical vibrations, is on the counter. Because the parts to be cleaned are small, only a beaker full of detergent solution is needed. The ultrasonic energy is readily transmitted through the glass beaker, the latter being immersed in the tank full of tap water. The tank/transducer is of welded stainless steel and will withstand alkalis, detergents, and mild acids; however, in processing tiny components or when strong acids are needed, coupling into a secondary glass vessel is preferred.

Glass Chips in Sleeves Troublesome

Another hard-to-clean component in diode production is a glass sleeve, ⅜ in. long, with a ⅛-in. OD and a 1/16-in. hole. (In some styles, the sleeves are even smaller, having an ID of 1/32 in.) As one can readily imagine, getting chips out of the hole was extremely difficult, but ultrasonic cleaning does it easily.

Formerly, the glass sleeves were boiled in detergent solution for 10 to 15 minutes, hoping that the bubbling action would be enough to remove all chips. Judging by the number of sleeves which had to be recleaned, it wasn't.

Now, glass sleeves are individually racked, immersed in boiling detergent solution for 5 minutes, then subjected to a 3-minute ultrasonic cleaning bath. Thus, the time to clean sleeves *once* is not much less, but none have to be cleaned twice. Now only a 5-per-cent random sample is checked, because the reject rate has practically disappeared.

Metal Stampings

Still a third application for ultrasonics is in cleaning rare-metal stampings. The company uses very thin platinum for the contact-making S-spring, and a tiny disk of gold foil to secure the silicon wafer in place. (See Fig. 3) In stamping out these metals, they are contaminated with die lubricants, all of which must be removed. Three to five minutes in an ultrasonically agitated solvent, acetone or trichlorethylene, and the stampings are surgically clean.

Ultrasonic Energy Improves Plating

In addition to cleaning, the company has also found that ultrasonic energy improves plating deposits as, for example, in gold-plating both sides of 0.010-in. disks. Not only is the process much faster, but the de-

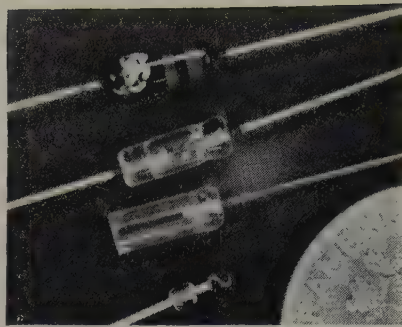


Fig. 3 — Extreme minuteness of diode components is shown by comparison with dime. Contact-making platinum S-spring is visible at the top, and inside glass sleeve, center. Ultrasonic cleaning of components means fewer "leakers", more reliable operation of diode.

posit is denser, more uniform than any achieved before.

Electronic Product to Help Electronic Manufacture

Generating ultrasonic energy is in itself a development of the electronic engineer. The equipment used in cleaning the diode components consists of two basic units: the generator, to convert 60-cycle 110-v ac into 38-kc electrical energy, and the piezoelectric transducer which transmits mechanical vibrations of the same frequency into the cleaning fluid.

A typical ultrasonic generator[2] uses three major components: a type 812-A triode, a power transformer, and a special heavy-duty coil. In addition, the generator also incorporates an 11-position tuning switch to permit selection of the most efficient cleaning frequency, in the range of 36 to 40 kc.

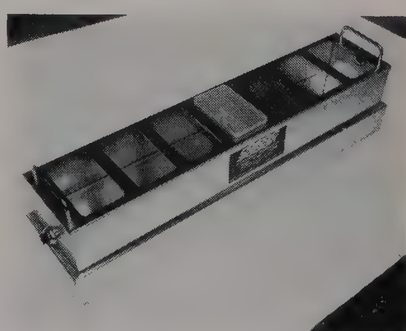
The tank-transducer is an integral unit, a stainless steel tank with a number of bottom-rounded barium titanate crystals. These change slightly in size when a voltage is impressed across two opposite, polarized faces, and thus set up mechanical vibrations directly equivalent to the applied frequency. If enough energy is supplied for this given frequency, cavitation will be produced. Cavitation is the rapid build-up and sudden collapse of voids within the liquid, called implosions, which have a highly erosive action. In effect, they act like thousands of tiny scrub brushes, and literally blast insoluble soils off the surface to be cleaned.

Humidity Test Proves Superior Results

Each diode must pass a humidity test, which is meant to bring out the tiniest flaw leading to subsequent service failure. Diodes are subjected to 100 per cent relative humidity at a high temperature for 24 hrs, then both temperature and humidity are reduced for a day. This cycle is repeated several times, and then the breakdown voltage of each diode is analyzed on an oscilloscope. A diode whose glass-to-metal shell is not perfect will not pass this inspection because the slightest trace of moisture will show up as a soft rather than a sharp breakdown curve. Since instituting ultrasonic cleaning procedures, the reject rate due to "leakers" has been insignificant.

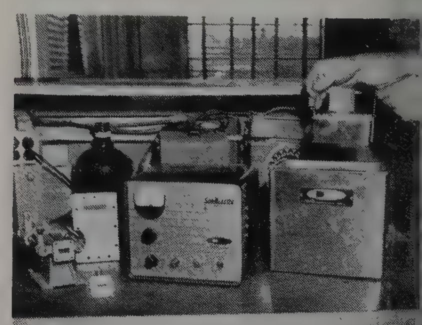
[2]Model AP-25-B Sonogen

Ultrasonic Cleaners



Courtesy Branson Ultrasonic Corp.

Tank designed specifically for semiconductor etching and cleaning operations. Dimensions are 6½" x 32" x 4". Removable cover holds up to 7 plastic beakers. Energy can be transmitted into an acid contained in the plastic beaker.



Courtesy Narda Ultrasonics Corp.

The Ultrasonic cleaner shown above consists of a generator and tank. The tank is filled with the desired cleaning solution and at the flip of a switch high speed precision cleaning is effected. The generator can activate a second type if desired.

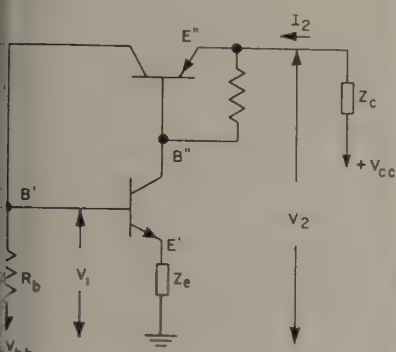
›rrespondence . . .

‡ Hook Transistor Thyratron

a recent paper[1] Shockley and Gib-›s, describing the properties of the ·· layer diode, point out that it acts › two interconnected complementary ›isistors.

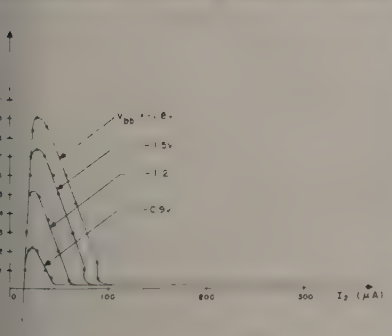
›he circuit of the hook common emit-› configuration (*Fig. 1*) was investi-›d by us some time ago[2] and it was ›wn that if the parameters of the two ›ponent transistors are identical and $= 0$, the output resistance in the ac-› region is

$$R_{out} = r_m + r_c/2 \tag{1}$$



. 1—Circuit diagram

› static characteristic is of the open ›uit stable type and its peak and ›ley points depend upon the input ›s (*Fig. 2*). In particular, the unit may › used as an inexpensive thyratron, ›ose "break" voltage is controlled by › input current I or by the voltage . In fact, the break voltage occurs ›en the input bias voltage, $V_1 = -V_{bb}$ R_bI is in a forward direction. The ›racteristics of *Fig. 2* were obtained



. 2—Static characteristics

›ng germanium transistors (2N28-›45), which possess high reverse cur-›t. The negative resistance is of the ›er of 0.5 meg, except where ava-›che phenomena occur, in which case ›s extremely high. From the point of ›w of switching, silicon transistors ›ear more suitable, because of their ›er reverse current.

Lucio M. Vallese,
Polytechnic Institute of B'klyn.

›m. Shockley, J. F. Gibbons—"Introduc-› to the Four-layer Diode" *Semiconductor ›ducts*, No. 1, Jan. 1958, p. 9-13.
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New Literature

Data Sheet 170 (Chicago Telephone Supply Corp.) illustrates and gives full technical details on the new CTS line of smaller space factor, more stable bobbin-less precision wire fixed resistors.

For further information, check No. 50 on Reader Service Card.

A new six page bulletin describing industrial ceramics, ferrites and custom services offered by Thermo Materials, Inc., is now available from the firm.

For further information, check No. 51 on Reader Service Card.

Bulletin AWH RC-301 is the catalog designation of the new A. W. Haydon Company sub-miniature hermetically sealed repeat cycle timers.

For further information, check No. 52 on Reader Service Card.

A special bulletin, No. 257, has been issued by General Instrument Corp.'s Radio Receptor subsidiary giving high temperature derating curves of the new vacuum-processed, high current density, Radio Receptor "Petti-Sel" selenium power rectifiers. The data supplements the specifications in Bulletin 248A.

For further information, check No. 53 on Reader Service Card.

A paper on Capacitors as Applied to the Electronics Industry is available from Vitramon, Inc., manufacturers of capacitors. This article provides excellent engineering information on the various types of capacitors and their characteristics.

For further information, check No. 54 on Reader Service Card.

A new Raytheon Diode Interchangeability Chart was announced recently to Raytheon's Industrial tube and Semiconductor Products Distributors. This new chart has been designed as a quick and ready reference in determining direct replacements for diode types.

For further information, check No. 55 on Reader Service Card.

Data Sheet 134 illustrates and describes the new seamless non-shock sensitive non-retentive Netic magnetic shields (Magnetic Shield Div., Perfection Mica Co.) designed for attenuating both high and low frequencies of substantially increased transformer radiation in transistorized power supplies.

For further information, check No. 56 on Reader Service Card.

A brochure describing waveguide pressure windows and their uses has been prepared by Microwave Associates, Inc. Performance curves, outline dimensions and drawings, and complete electrical and mechanical data are given.

For further information, check No. 57 on Reader Service Card.

A report outlining the properties of silicones as lielectric materials has been prepared by the Dow Corning Corporation.

or further information, check No. 58 on Reader Service Card.

General Transistor Corporation, offers a new welve page brochure describing their high frequency ransistors. The brochure gives maximum ratings, ut-off and small signal characteristics, and charts howing the common emitter output static characteristics.

For further information, check No. 59 on Reader Service Card.

New 1958 Catalog No. 102 has just been released by Hermetic Seal Transformer Company. Listed, illustrated and described are 390 stock and many special-application components.

For further information, check No. 60 on Reader Service Card.

Bulletin 109, a one-page summary of available high emperature ceramic materials available from Duramic Products Division, Technion Design & Manufacturing Co., Inc.

For further information, check No. 61 on Reader Service Card.

Electronic Research Associates, Inc., transistorized equipment manufacturers, announces the availability of a new, 10-page, multi-color, folder type catalog. This new catalog covers ERA's complete line of products.

For further information, check No. 62 on Reader Service Card.

The Instrument Division, Sun Electric Corporation, Chicago, announces a new illustrated catalog featuring their complete line of electrical indicating instruments in both Ruggedized, conforming to Military Specification MIL-M-10304 and Commercial types.

For further information, check No. 63 on Reader Service Card.

Second Edition of D.A.T.A.'s Semiconductor Diode & Rectifier Lists will be on display at the IRE Show, Booth 3035, this comprehensive tabulation of Semiconductor Diodes & Rectifiers includes approximately 1900 different types of 47 manufacturers—an increase of more than 450 types since the first Edition in September.

For further information, check No. 64 on Reader Service Card.

Sprague Engineering Bulletin October 1957 has an interesting article on solid electrolyte tantalum capacitors.

For further information, check No. 65 on Reader Service Card.

The High Frequency Induction Heating Review, February 1957 a periodical published by Lepel High Frequency Laboratories, Inc., contains an interesting article, "Induction Heating in Transistor & Diode Manufacture."

For further information, check No. 66 on Reader Service Card.

International Rectifier News, Dec-January 1957-58, published by the International Rectifier Corp., contains 2 interesting articles, "45 and 52 Volt Selenium Rectifier Cells," and "Zener Regulated Diodes."

For further information, check No. 67 on Reader Service Card.

Industry News

Based on a compilation by the Electronic Industries Association (formerly RETMA), estimated Department of Defense electronics expenditures in major categories of military functions increased substantially in the fourth quarter of fiscal year 1957 to bring the total spent for electronics during that fiscal year to $3.506 billion—far exceeding the $2.802 billion spent for electronics by the military in fiscal year 1956.

The $3.506 billion electronics spending in FY 1957 represents the largest amount spent by the military for electronics in a single year in history—bringing the total spent since 1951 to $18.687 billion, according to the EIA formula and computation.

Intended primarily to be used to depict trends, and subject to later revision, the EIA compilation shows the following electronic figures (in millions of dollars) for fiscal year 1957, ended June 30, 1957:

Budget Category	1st quarter	2nd quarter	3rd quarter	4th quarter	FY 1957
Aircraft	$213	$270	$258	$342	$1,083
Ships-harbor craft	17	19	22	23	81
Combat vehicles	2	2	2	1	7
Support vehicles	—	1	1	1	3
Guided missiles	205	259	311	333	1,108
Elec. & Comm.	130	236	251	263	880
Research & Dev.	65	76	80	82	303
Miscellaneous	5	13	13	10	41
TOTAL	$637	$876	$938	$1,055	$3,506

The above chart compares with the following EIA compilation of military electronics spending for fiscal year 1956 (also in millions of dollars):

Manufacturers sold more than double the number of transistors in 1957 than during the previous calendar year, the Electronic Industries Association reports. A similar increase had been recorded by EIA for the calendar year 1956, indicative of the continued rise in application of the semiconductor device.

Manufacturers sold 28,738,000 transistors in calendar year 1957 with a dollar value of $69,739,000 compared with 12,840,000 transistors sold in 1956 worth $37,352,000, EIA said.

Factory sales of transistors totals 2,773,000 units with a dollar value of $6,619,000 in December compared with 3,578,700 units sold in November with a dollar value of $6,989,000. This compared with the 1,608,000 units sold in December 1956 worth $4,691,000, EIA reported.

The following EIA chart shows transistors sales ıring December and the calendar year 1957 (units .d dollars):

	1957 Sales (units)	1957 Sales (dollars)	1956 Sales (units)
ınuary	1,436,000	$4,119,000	572,000
ːbruary	1,785,300	5,172,000	618,000
arch (5 wks)	1,904,000	5,321,000	708,000
ɔril	1,774,000	4,880,000	832,000
ay	2,055,000	5,636,000	898,000
ıne (5 wks)	2,245,000	6,121,000	1,130,000
ıly	1,703,000	4,216,000	885,000
ugust	2,709,000	6,598,000	1,315,000
ptember wks)	3,231,000	6,993,000	1,115,000
ctober	3,544,000	7,075,000	1,290,000
ovember	3,578,700	6,989,000	1,829,000
ecember wks)	2,773,000	6,619,000	1,608,000
TOTAL	28,738,000	$69,739,000	12,840,000

The 1958 *Armed Forces Communications and Elec-onics Association's* Exhibit to be held in the Hotel ıeraton Park, Wash., D. C., in conjunction with FCEA's 12th annual convention June 4-6.

The convention program has been planned to in-ude rocket industrial and mobile communications, actical applications of electronics in medicine, tran-stor applications (solid state physics) in military ectronics, computer control in satellite measure-ents, computer use in stock control methods, and ːw uses of printed circuits.

Semiconductors as sources of rectified power are ːre to stay, R. M. Crenshaw and A. L. Munn, Gen-ral Electric Company engineers, reported at the Vinter General Meeting of the American Institute Electrical Engineers.

The authors pointed out however that despite the ıcreasing popularity of semiconductor rectifiers, ıere are approximately 8,000,000 kw of mercury arc ːctifiers in service in the United States, compared rith less than half a million kw of all types of semi-onductor rectifiers. The mercury arc rectifier has een the most important source of direct current ower in the electrochemical industry, but "semi-onductor rectifiers are destined to furnish a much ırger proportion of future loads," they said.

A comprehensive 55 session program (see page 63), ıvolving some 280 papers ranging over 27 fields of adio-electronics, has been set for the 1958 IRE Na-ional Convention on March 24-27 in New York City. 'hirty-three sessions will be held at the Waldorf-As-oria Hotel and 22 at the New York Coliseum. A ecord-breaking attendance of 55,000 engineers and cientists from 40 countries is expected.

The Microwave Research Institute of the Polytech-ic Institute of Brooklyn plans to hold the Eighth in s series of Annual International Symposia in New 'ork City on April 8, 9, 10, 1958. This symposium will eal with the interaction of electro-magnetic fields nd electron or plasma beams in general waveguide egions herein termed *electronic waveguides*. The lat-er are to be understood in a general sense as open or losed waveguide regions in which there exists the ossibility of relative motion between an electro-ıagnetic wave and a system of charge particles.

On Microformed Metals for Semiconductors

EDWIN S. KENT*

The choice in semiconductor devices at present are germanium for its high frequency properties, and silicon for its greater efficiency at higher temperatures. Experimentally other compounds show the high frequency properties of germanium at the temperatures where silicon devices work best, but for the purpose of description these two basic elements are used as examples.

Microforms of pure germanium and silicon are cut from single long crystals grown from zone-purified metals. The crystals are first started as seeds and pulled from their melts at about 1 mm per min. Purified germanium, or silicon, must be inoculated during crystal growth with precise amounts of doping elements, which either donate electrons to cross-sections of the growing crystal or take electrons out. Donor dopes include antimony, arsenic, bismuth, phosphorus. Acceptors include boron, gallium, indium.

Junctions of types *p* or *n* are created in the crystal by letting pellets or spheres of the appropriate inoculant slide down a tube into the melt intermittently. Microforms cut from such doped germanium or silicon crystals grown by this method have either *n* or *p*, or both junctions grown into them.

Other devices use microformed wafers of pure germanium or silicon to which the impurity is fused. For example, a pellet of indium is placed on a wafer of *n*-type germanium. The unit is slowly heated. At 156° C the indium melts into a tiny blob. As the temperature continues to rise the spot of germanium on which the indium rests begins to melt and dissolve up into the molten indium, making an indium-germanium alloy. At 500° C, heating is stopped and the unit allowed to cool slowly. The germanium settles out of the alloy and grows back into its original *n*-type crystal base. But the regrown spot of germanium is now *p*-type because it is contaminated with some atoms of indium, and the whole germanium wafer includes a *p-n* junction. The re-solidified indium blob on top makes an excellent connection to the junction.

Microforms used to alloy, solder, seal and otherwise serve in semiconductor devices must be extremely precise in the quantities of elements of which they are made. Most must be so small that they can be manipulated only under magnifying glasses. A few of the shapes in demand are discs, pellets, spheres, washers (see *Fig. 1*). These measure from 0.001 inch to 0.04 inch in thickness, from 0.01 inch up in diameter. In, say, antimony-doped germanium an impurity diffusion layer can be created 1.5×10^{-4} *cm* thick.

In addition to the simple elements many alloys heretofore scarcely known and still incompletely understood are being used in research, engineering and development. Such alloys, to list only a few binary ones, include indium with gallium, tin, lead, germanium, gold, silver, zinc and cadmium; lead with arsenic and antimony; aluminum with gallium and indium; tin with gallium, lead, bismuth, antimony, gold, silver and arsenic; silver with arsenic and copper; gold with arsenic, antimony and gallium.

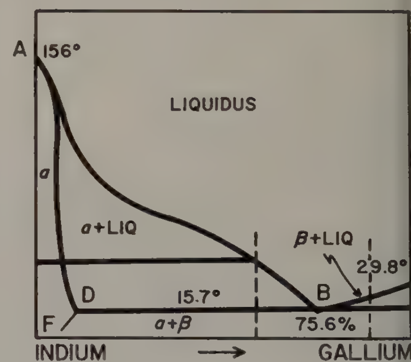


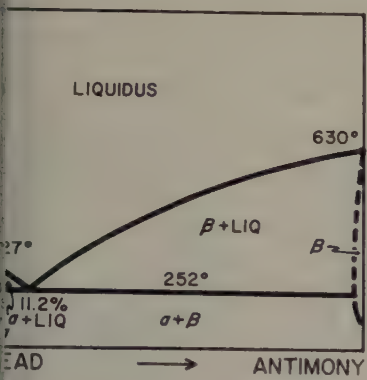
Fig. 2—Indium-Gallium system.

To produce the alloy prescribed for a particular use the metallurgist must know the proportions of the elements at the temperatures where their mixtures solidify out of the melts. This data has been recorded for many binary, ternary and quatenary alloys, and charted as equilibrium diagrams.

* *Anchor Metal Co., Inc.*

Fig. 1—Various microforms.

is quite helpful for engineers erned with semiconductor re- ch to have a fundamental work- knowledge of the information can be obtained from equilib- n phase diagrams and the me- nics of obtaining the information. ake, for example, the system In- n-Gallium shown in *Fig. 2.* This em is typical of a group of binary ems in which the components are cible in the liquid state and only ially miscible or immiscible in solid state. Line ABC represents liquidus line, line DE the solidus , and line ADF the limit of solid



ig. 3—Lead-Antimony system.

ibility of gallium in indium. The dus line DE exists at 15.7° C for system. This temperature is ed the eutectic temperature for system and may be defined as lowest temperature at which a iid phase may exist.

f we examine the progressive ling of an alloy of say 90% in- m-10% gallium we find the fol- ing phenomena occurring: The iid will continue to cool until it ches the temperature represented the crossing of line BC or at about C. At this point the gallium is longer completely soluble in the lt and will begin to crystallize out the melt. The cooling will con- ie with successive gallium crys- ization until the eutectic tem- ature of 15.7° C is reached. At s point the melt will have a com- ition equivalent to point B, the ectic composition, and the cool- will continue isothermally until entire melt has solidified.

f we examine the cooling of an y of say 60% indium-40% gal- n we find the following: The iid will cool until it reaches the perature represented by the ssing of line AB or at about 32° C. this point the indium is no longer ible in the melt, however some centage of gallium will form a d solution in indium as repre- ted by line ADF and so the crys- coming out of the metal will be

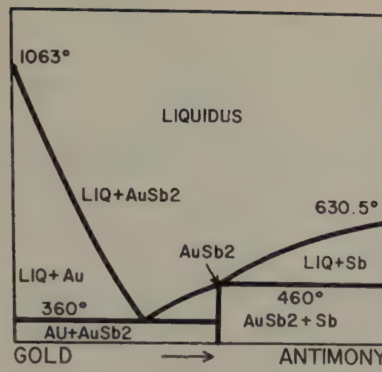


Fig. 4—Gold-Antimony system.

a solid solution of gallium in indium. The cooling will continue again until the eutectic temperature is reached at which point the cooling proceeds isothermally until the entire melt is solidified.

It is therefore evident that an alloy of 75.6% indium and 24.4% gallium has no plastic range. This alloy is known as the eutectic alloy for the system. It is worthy of note at this point that microscopic examination of the solid metal will show a definite difference in crystal size between the metal solidified in the plastic range of the cooling curve and that part solidifying at the eutectic temperature. The metal will show coarse crystals of either solid solution or gallium (depending on the alloy) and fine crystals representing the eutectic composition of the system.

The system Lead-Antimony (*Fig. 3*) is essentially the same as the Indium-Gallium except for the occurrence of two solid solution phases; therefore the solid metal will consist of solutions of antimony in lead and lead in antimony.

At 327° C lead starts to settle out of the Pb-Sb liquidus (melt). This is the alpha phase of the solidifying alloy. Antimony, as shown at the other side of the diagram, has already been settling out of the liquidus as it cooled below 630C. This is the beta phase. At 252° C the alloy is all solid. It is a homogeneous mixture containing 11.2 percent lead with 88 percent antimony.

The system Gold-Antimony (*Fig. 4*) presents one additional complication—the formation of the intermetallic compound gold stibnite. For ease in understanding and in handling the phase diagram in this case it is convenient to divide the diagram in two, considering two separate systems—Gold-Gold Stibnite and Gold Stibnite-Antimony. In this way it can be seen that the diagram then reverts to the systems outlined above and is handled the same way.

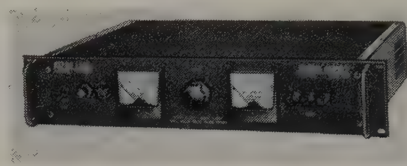
New Products

Transistorized V.R. Power Supply

Kepco announces the release of a new tubeless transistorized voltage regulated power supply featuring excellent regulation, low ripple content, fast recovery time, good stability, and low output impedance.

The Model SC-32-1 delivers 0-32 volts, 0-1 ampere. Regulation for line or load is less than 0.03% or 0.003 volts, whichever is greater. Ripple is less than 3 millivolts RMS. Recovery time is less than 50 microseconds. Stability for eight hours is less than 0.03% or 0.003 volts, whichever is greater. Output impedance is less than 0.01 ohms.

For further information check No. 108 on Reader Service Card

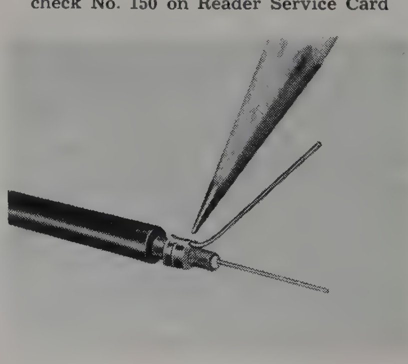


Solderless Terminals and Connectors

Amp Incorporated, manufacturer of solderless terminals and connectors announced it will unveil its all new Automachine Shielded Wire Ferrule for automated pigtailing during the IRE Show this March in New York.

Designed expressly for grounding the shield braid of coaxial conductors, the new automachine feeds and attaches Automachine Shielded Wire Ferrules and pigtails simultaneously to shielded wire leads. The automachine's dual applicator permits attachment of ferrule and pigtail wire to a double ended shielded wire jumper or to two shielded wire leads at the same time, with pigtail wires whose length can be adjusted in the applicator.

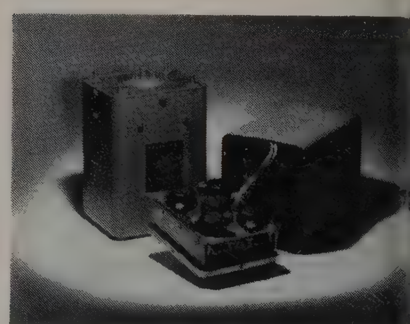
For further information check No. 150 on Reader Service Card



Silicon Voltage Regulator and Reference Zener Diodes

A complete line of Silicon Zene voltage regulator and referenc diodes comprised of a series of type in each of seven styles will be intro duced at the IRE show in New Yor by International Rectifier Corpora tion, El Segundo, California. Thi listing of 64 types includes: minia ture types rated at 500 milliwatt standard top-hat style with pigta leads rated at 1 watt, 3.5 and 1 watt types featuring stud construc tion, double-anode types rated at 35 milliwatts, 5 watt multiple junctio high voltage types and the IN43 IN430A and IN430B reference ele ment types. All diodes in this grou are designed and manufactured t meet the most rigid military specifi cations. High temperature operatio (−65°C to +150°C) and high loa current capacity result from a mo advanced thermal design. Sharp re verse breakdown characteristic provide stable voltage regulation.

For further information check No. 116 on Reader Service Card



Transistorized Power Packs

New developments in advanc circuitry and improved transist types has made possible Electron Research Associates regulated sem conductor power supplies whi permit full input voltage to repeatedly applied and abruptly di connected without deterioration performance.

Available in 150 VDC and 3 VDC ratings 0-100 milliamperes. I put is 105-125 VAC, 60 or 400 c Regulation is better than 0.1 Ripple less than 0.02%. Units a sealed in transformer type housin but transistors and circuits are a cessible for replacement.

For further information check No. 102 on Reader Service Card

ındardized Diode for rowave Measurements

new microwave crystal simpli- microwave power measurements allowing quantitative use of out- voltages. Developed by Micro- re Associates, Inc. the MA-424 vides standardized law of detec- and output voltage over a wide ge of input power. Applications ude instruments for measuring rowave power, voltage, imped- e, power ratio and systems for rowave AGC and other types of trol which rely on quantitative tionships between input micro- ve power and resulting rectified .

For further information
heck No. 120 on Reader Service Card

ode Tester

Speed and convenience in produc- n testing are combined with labo- ory precision in the new TLI del DT-257 Diode Tester (Tele- nics Lab. Inc.,) designed to easure the characteristics of dium and low-power semi con- ctor diodes. A simple lever switch provided which automatically ects the desired test voltage and ter ranges for both forward and verse tests. The reverse voltage pply is regulated to 0.5%. Either e of three preset voltages or a con- uously variable voltage covering e range from 0 to 150 volts may selected. The forward voltage pply is continuously variable from to 2 volts. The accuracy of the ltage and current meters is ± 2%.

For further information
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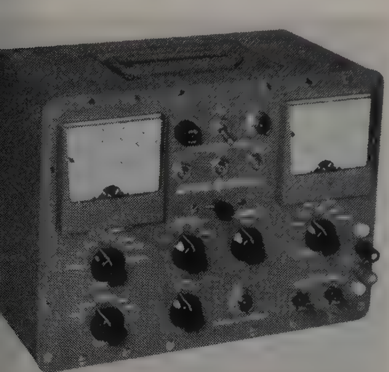
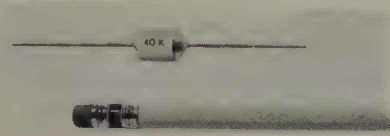


Silicon Rectifier

A silicon rectifier featuring 750ma to 55°C (No heat sink), axial leads, high efficiency, positive seal, instantaneous polarity has been added to the Tarzian line. The "K" series incorporates a positive "environmental seal" with special epoxy resin. Polarity is identified by color coded resin at each end. Voltage ratings are 100, 200, 300 and 400 volts peak inverse.

For further information
check No. 143 on Reader Service Card



Programmable, Regulated Power Packs

Electronic Measurements Co., Inc. announces the addition of two new models to their line of regulated, programmable power packs. The new power packs double the voltage range of previous models.

Model 235A has a programmable output capable of furnishing 500 *ma* at any voltage between 0 and 600. Model 236A (illustrated) is rated at 0 to 600 V *d-c* at a maximum current of 200 *ma*. The Model 236A also has a 0—150 V *d-c*, 5 *ma* bias supply and a 6.3 V *a-c* CT, 10 amp filament supply.

For further information
check No. 151 on Reader Service Card

New Germanium Photodiode

External light-focusing devices or optics are unnecessary with a new Germanium Photodiode announced by Nucleonic Products Co. of Los Angeles. The hermetically sealed, high-sensitivity device features a narrow, integral lens which accurately concentrates light on the sensitive portion of the junction area. It can be used in either the visible or infra-red portions of the spectrum—wherever rapid, high-sensitivity scanning or reading is required.

For further information
check No. 118 on Reader Service Card

Glass Dielectric Capacitors

The JFD Split bushing Panel Mount Series provides a variety of Trimmer Capacitors to meet the peculiar needs of Critical Circuits. Features of the capacitors are: High dielectric constant glass is matched with a precision tuning assembly to provide a maximum tuning range for minimum physical size. Matched temperature coefficients are available due to choice of brass and invar combination assemblies. 24 karat gold plating for noise-free tuning and minimizing of thermocouple effects caused by dissimilar metals in contact. Special alloy undercoating to protect all metal parts from corrosion and permit use under extreme environmental conditions.

For further information check No. 109 on Reader Service Card

Multi-Purpose Silicon Diode

General Instrument Corp.'s Semiconductor Division, through its Radio Receptor Co. subsidiary, has brought out a new, extremely versatile, multi-purpose subminiature silicon junction diode for computer, communications, military and general circuit requirements, as well as moderate power applications. The new diode will handle an average rectified current of 200 *ma* and has a power dissipation rating of 200 *mw*. Its operating temperature range is from —65 to 175 degrees C. Forward voltage drop is under 1 volt at 100 *ma*, with a .3 μsec reverse recovery. Peak inverse voltage is 120 volts, with a reverse leakage of .05 μa at —50 volts and 25 degrees C., and 25 μa at —50 volts at 150 degrees C.

For further information check No. 137 on Reader Service Card

Oil-Tight Indicator Lights

The Dialight Corp. announces a new series of Oil-Tight Indicator Lights for use in heavy-duty industrial applications. These units are permanently oil-tight, water-tight, and dust-tight, thanks to the newly-designed bushings and lens caps. These components are made of 1-piece solid brass and are fully gasketed, in a special manner, with oil-proof gaskets. All gaskets are retained, thus preventing loss of seal. Other advantages include: High impact phenolic insulation, streamlined design, compact shape, and rugged construction to withstand severe vibration conditions.

For further information check No. 147 on Reader Service Card

Micro-Miniature Transistors

The three new varieties of micro-miniature transistors are available from Philco. These are types 2N534, a high voltage (50 V) version of the basic low level audio transistor; 2N535, a unit with high maximum temperature (85° C) and collector voltage (20 V) ratings; and 2N536, a unit specified for switching applications. Other micro-miniature transistors in the Philco "family" available in the miniature M-1 can are type 2N207, a low level audio frequency germanium PNP transistor and types 2N207A and 2N207B, low noise versions of 2N207.

For further information check No. 125 on Reader Service Card

Tantalum Capacitors

Texas Instruments' Semiconductor Components Division announces a line of solid tantalum electrolytic capacitors primarily designed for use in miniaturized circuitry where both reliability and temperature stability are vital factors, these new devices, named *tan-Ti-cap* capacitors, are immediately available in 18 ratings. Five *tan-Ti-cap* capacitors are six-volt units ranging from 22 to 200 microfarads, five are 15-volt devices from 10 to 100 microfarads, five are 25-volt capacitors from five to 55 microfarads, and four are 35-volt units from four to 25 microfarads.

For further information check No. 141 on Reader Service Card

High Voltage Cartridge Silicon Rectifiers

Pacific Semiconductors, Inc. has announced a new line of very high voltage cartridge silicon rectifiers. Voltage range is from 1500 to 16000 volts, at temperatures to 150°C.

The eighteen types in the new line meet or exceed E1A specifications in the 1N1133 to 1N1149 series. The units are highly ruggedized with all connections between component diodes firmly bonded within a high impact sealed sleeve.

For further information check No. 122 on Reader Service Card

Matched Pair Power Transistors

Two germanium power transistors supplied in matched pairs have been added to the product line of the Bendix Aviation Corporation. The transistors are electrically matched to provide low distortion in audio and servo applications requiring push-pull amplification.

The units, designated 2N399 and
N401, are rated at 8 watts of un-
storted Class B push-pull output
wer. Each unit can dissipate up
25 watts. The 2N399 is a high-
in unit, and the 2N401 has a
edium-gain power output. They
ature welded construction with a
rmetically sealed cover.

For further information
check No. 117 on Reader Service Card

ower Transistor

A new power transistor announced
y Delco Radio Div., Gen'l Motors
orp., has been labeled the DT80. It
as an 80-volt collector diode rating
nd offers a high DC gain range.
ain at 1.2 ampere range is 100,
nd, like other Delco Radio tran-
stors, gain spread is held to a two-
-one ratio. The DT80 features low
turation resistance, allowing the
andling of up to 13 amperes from
e usual 12 and 28 volt DC sources.
his low saturation resistance makes
ven a six-volt source practical for
igh power applications. The DT80
ansistors will be supplied either in
ngle units or matched pairs.

For further information
check No. 101 on Reader Service Card

iffused Junction Rectifier

A new diffused silicon junction
ectifier for high current applica-
ions has been announced by the
Trans-Sil Corporation of Englewood,
New Jersey. The new device is
available in models up to 100
mperes @ 600 P.I.V., 250 amperes
@ 600 P.I.V., and 400 amperes @ 350
P.I.V. Power supply applications re-
quiring as much as 5,000 amperes
apacity can be handled by stacked
ombinations. Lower current pack-
ged stacks (from 2 amperes) are
lso available.

For further information
check No. 115 on Reader Service Card

Mounted Stored Energy Welder

Federal Tool Engineering Co., Cedar Grove, New Jersey, announces the development of a new "Tweezer-Weld" product. This new, complete bench mounted stored energy welder, Model DC 80, permits the welding of copper, silver, tungsten, molybdenum, etc., the discharge time of 0.0008 to 0.0012 second insures reliable welds without discoloration, excessive deformation or metallurgical change.

For further information
check No. 113 on Reader Service Card

Index to Advertisers

surface barrier transistors from SPRAGUE

2N344/SB101
for Medium Gain Amplifiers

	Min.	Typ.	Max.
h_{fe}	11	23	83
f_{max}	30	45	—

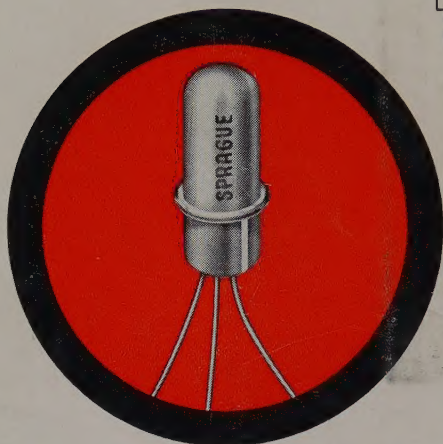
2N345/SB10
for High Gain
Amplifiers

	Min.	Typ.	M
h_{fe}	25	40	1
f_{max}	30	45	

actual size

2N346/SB103
for High Frequency Oscillators

	Min.	Typ.	Max.
h_{fe}	10	—	—
f_{max}	60	90	—



2N240/SB512
for Computer
Switching

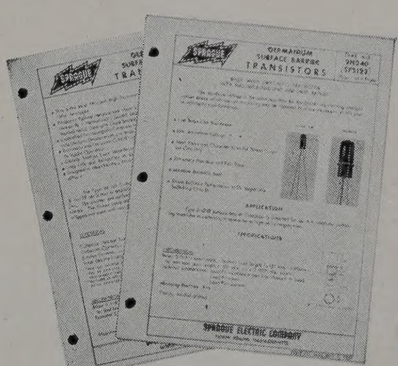
	Min.	Max
h_{fe}	16	—
f_{max}	30	—
T_s	—	80

IN VOLUME PRODUCTION *Now!*

For general high frequency applications, and for high speed computer switching circuits, design around Sprague surface barrier transistors. They are available now in production quantities from a completely new, scrupulously clean plant, built from the ground up especially to make high quality semi-conductor products.

The four transistor types shown are the most pop lar. Orders for these units are shipped promptl What's more, surface barrier transistors are reaso ably priced. High quality and excellent electric characteristics make them an economical solutic to many difficult circuit requirements.

Sprague surface barrier transistors are fully censed under Philco patents. All Sprague and Philc transistors having the same type number are man factured to the same specifications and are ful interchangeable. You have *two* sources of supp when you use surface barrier transistors!



WRITE FOR COMPLETE ENGINEERING DATA SHEETS ON THE TYPES IN WHI YOU ARE INTERESTED. ADDRESS REQUEST TO THE TECHNICAL LITERATU SECTION, SPRAGUE ELECTRIC CO., 467 MARSHALL ST., NORTH ADAMS, MA

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